Vol. 2. No. 3. December, 1958.

23
Aus. Hb

THE NEW ZEALAND ENTOMOLOGIST

THE JOURNAL OF THE ENTOMOLOGICAL SOCIETY OF NEW ZEALAND.

PUBLISHED BY THE SOCIETY.

COPIES OBTAINABLE FROM THE EDITOR.

PRICE : FIVE SHILLINGS

THE ENTOMOLOGICAL SOCIETY OF NEW ZEALAND

OFFICERS:

President: D. SPILLER, Ph.D.,

Plant Diseases Division, D.S.I.R., Auckland

Vice-President: R. HARRISON, M.Sc.,

Plant Diseases Division, D.S.I.R., Auckland

Secretary-Treasurer: A. D. LOWE,

Entomology Division, D.S.I.R., Ashburton

Editor: B. B. GIVEN, M.Sc.,

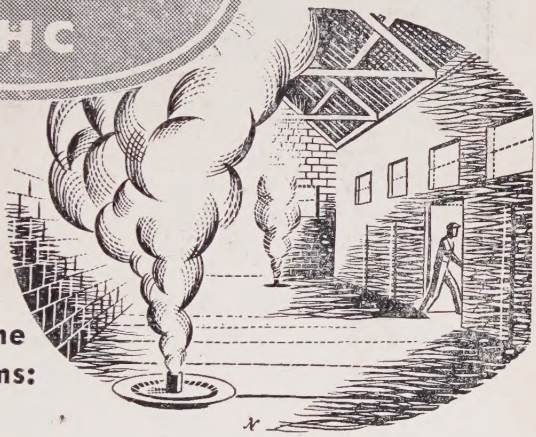
Entomology Division, D.S.I.R., Box 223, Nelson

Are any of these pests your worry ?

COCKROACHES	FLIES
SILVERFISH	ANTS
STEAM FLIES	FLEAS
WOOD BEETLES	MOTHS

'GAMMEXANE'
containing
Gamma Isomer BHC

will control them Economically Safely Easily



For Farm, Industrial and Domestic Use. Available in the following forms:

"GAMMEXANE" Smoke Generators For Large, Enclosed Areas.

"GAMMEXANE" Insect Powder For Direct Dusting Application.

"GAMMEXANE" 25% Wettable Powder For Spray Application.

"GAMMEXANE" L 20 For Spray Application.

ICI

Available from Stock and Station Agents and Chemists.
If unobtainable in your district or if further information is required, write to—

IMPERIAL CHEMICAL INDUSTRIES (N.Z.) LTD.

P.O. Box 1592 Wellington | *P.O. Box 900 Auckland* | *P.O. Box 1486 Christchurch*

If you want to measure pH

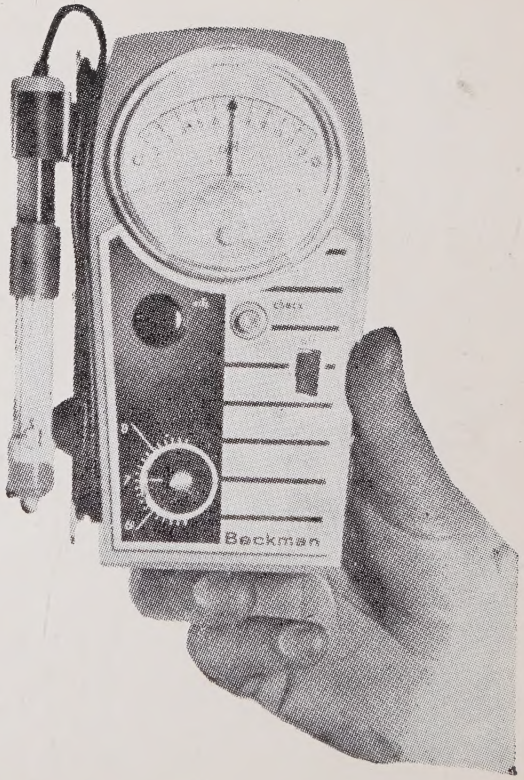
with

- **a good standard instrument**
- **a super-accurate meter**
- **a push-button, automatic job**

or

- **a pocket pH meter**

then WATVIC can supply just what you need. pH meters are, of course, just one item of the most comprehensive range of scientific and laboratory equipment offered by any scientific supply house in New Zealand.



WATSON VICTOR
LIMITED
(INCORPORATED IN NEW SOUTH WALES)

AUCKLAND
6-10 Kitchener St.,
Phone 31-710.

CHRISTCHURCH
80 Chester St.,
Phone 75-983.

WELLINGTON
16 The Terrace,
Phone 42-095.

DUNEDIN
355 Great King St.,
Phone 76-010.

THE

NEW ZEALAND ENTOMOLOGIST

Vol. 2. No. 3. December, 1958.

Exotic Millipedes (Diplopoda) in New Zealand

E. W. Dawson,

D.S.I.R., Wellington

Ten years ago when, at the sugestion of Dr. R. R. Forster, I was beginning a study of New Zealand millipedes, great difficulty was experienced in the ready identification of the most commonly distributed forms, those of the " juloid " kind with a circular cross-sectional appearance. Although my work has now led me along other paths since that time, I have been particularly concerned with the distribution of exotic millipedes and ants throughout New Zealand, and, thanks to the assistance of overseas colleagues, I am now able to give identifications of some of these species, and to offer some information about the introduction of certain European millipedes into New Zealand.

In a forthcoming basic checklist and bibliography of the Diplopoda of New Zealand further comments will be made, but, meanwhile, the publication of these records may stimulate those interested in the question of the wanderings of invertebrate " tramps " to make collections in suitable places. I would be very glad indeed to have specimens of such millipedes, preferably preserved in 70% alcohol and glycerine, from any part of the country, especially from the major ports of entry. Material may be sent to me at D.S.I.R., 177 Thorndon Quay, Wellington, and such assistance will be greatly appreciated.

Apart from the recent work on the oniscomorph millipedes by Holloway (1956) and the description of a new pselaphognath, *Propolyxenus forsteri,* by Condé (1951), the latest records of millipede distribution in New Zealand are to be found in Chamberlin's (1920) account of the " myriapods " of the Australian region. This forms the basis for a new study of New Zealand millipedes, although Chamberlin has omitted reference to a number of earlier described forms and appears to have incorrectly transcribed some locality labels, in two cases resulting in the incorrect formation of specific names. His list, together with the earlier overlooked species and the recently described forms, brings the known millipede fauna of New Zealand to a total of some 48 species. Some

of these are undoubtedly synonymous, and a number of new, supposedly indigenous, species await description, judging from material in hand.

Chamberlin (1920: 113–4, 158) has recorded the following exotic species in the New Zealand fauna: *Orthomorpha gracilis* (Koch, 1847), and *Ophyiulus pilosus* (Newport, 1842). Previous to this, Colenso (1894) had described *Spirostreptus fijiensis,* which had been found at Dannevirke among bananas from Fiji. It seems likely, however, that Colenso's specimen belonged to an already described Fijian species. Other spirostreptid and iulid millipedes have been described from New Zealand at various times and it again seems likely that they may belong to known European species. They include *Iulus berardi* Walckenaer & Gervais, 1847, *Spirostreptus antipodarum* Newport, 1844, *S. striatus* (Hutton, 1877). Similarly, the polyzonid *Rhinotus bivittatus* (Pocock, 1898), collected by Thilenius at Tauranga, and the polydesmid *Scynotus caesius* Karsch 1881, may not be indigenous species, but the specimens, at one time in the Berlin Museum, cannot be traced at present.

Preliminary remarks and results from a few collections are as follows:

Orthomorpha gracilis (Koch, 1847) [Polydesmidae], the cosmopolitan "hothouse millipede". Chamberlin (1920: 114) has recorded it from New Zealand: "Rotorna [*sic*] (W. M. Wheeler)." Causey (1943: 671), in her study of the ecology of the hothouse millipede, has given other details of interest and has included New Zealand within its range. Other details of its cosmopolitan distribution, morphology, and figures of the gonopods, may be found in Schubart's monograph (1934: 175–6, Figs: 282–3).

Nopoiulus venustas (Meinert 1868) [Blaniulidae]. Collected in grounds of Animal Ecology Section, Sydney Street, Wellington, by R. E. Brockie in the summer of 1957. Schubart (1934: 189–91, Figs. 302–4) recorded it as widely distributed in Europe, eastern U.S.A., Mexico and Chile, and he has provided figures of the gonopods and other morphological details.

Cylindroiulus britannicus (Verhoeff 1891) [Iulidae]. From leaves in garden litter, Waltham, Christchurch, by R. G. Frean, July 31, 1951; native bush, Kaituna Valley, Banks Peninsula, E. W. Dawson, April 26, 1953; native forest, Chandler's Mill, near Reefton, E. W. Dawson, June, 1955; grounds of Animal Ecology Section, Sydney Street, Wellington, R. E. Brockie, summer, 1957. Schubart (1934: 228–9, Fig. 361) gave the range of this species as including Europe, South Africa and India. These are the first known records from New Zealand. Figures of the gonopods and vulvae may be found in Schubart's account, and particularly in Rolfe's "Notes" (1937; 1938).

Ophyiulus pilosus (Newport 1842) = *O. fallax* (Meinert 1868); see Rolfe, 1934: 202 [Iulidae]. Records: "Wellington, Day's Bay, Rotorna [*sic*], Lake Takopema [*sic*], near Auckland, August, 1914 (W. M. Wheeler)" (Chamberlin 1920: 158); native bush, Kaituna Valley, Banks Peninsula, E. W. Dawson, April 26, 1953; native forest, Chandler's Mill, near Reefton, E. W. Dawson, June, 1955; grounds of Animal Ecology Section, Wellington, R. E. Brockie, summer, 1957. Schubart (1934: 268–72, Figs. 442–6) gave the range of this species showing that it is widely distributed in Europe. The general distribution includes Canada, the U.S.A., New Zealand, Tasmania (Schubart, *pers. comm.,* 1957), and India (Blower, *pers. comm.,* 1957).

Distribution and Economic Significance

The well known hothouse millipede, *Orthomorpha gracilis,* is "now widely distributed in greenhouses and is sometimes a serious pest" in England (Rolfe, 1937: 102). No information is available on the habitat of the specimens which Wheeler collected at what is, presumably, meant to be Rotorua, but the indications are that it was "out of doors".

Blower (1953: 313) has said of *Cylindroiulus britannicus,* a "reasonably common" millipede in Britain, that it has ". . . a distribution which often appears to indicate some connection with the influence of man. Hothouses, grave-yards, gardens and similar situations . . . seems to provide suitable habitats . . . There are exceptions to this type of distribution, however, and particularly so in Britain. *C. britannicus,* whilst almost exclusively confined to greenhouses, compost heaps and so forth in Germany (see Schubart, 1934) has been recorded from open country several times in Britain." Rolfe (1937: 102) has also recorded that this species "inhabits greenhouses and frames where it may be present in very large numbers". It has, according to Blower, "at some time or other, been accused of attacking crops".

Judging from this general association, the distribution of *C. britannicus* in New Zealand is rather curious and further collecting will, no doubt, make clear the details of this.

Rolfe (1934: 192) has called *Ophyiulus pilosus* "a fairly common British millipede", and has said that "All members of the Iulidae feed very largely on decaying vegetable matter, and when they occur as pests they are very often intensifying damage attributable primarily to some other cause" (1937: 103).

Recently, Helson (1955: 5) listed the occurrence of two specimens only of millipedes which had been intercepted by the Plant Quarantine Service between 1950 and 1953, and no millipedes at all are mentioned in lists of interceptions for 1951 to 1953 identified at the Plant Diseases Division (Jacks, 1953*a, b*; 1954). This may indicate that millipedes are not often accidentally intro-

duced into this country, but it appears clear that some of the common European potentially-harmful millipedes have been here for some time and are now well established although they do not, as yet, appear to have claimed the attention of those responsible for agricultural pest control.

It can be concluded, then, that the commoner millipedes of our towns and gardens are likely to prove to be introduced European or cosmopolitan species, and even in the native bush in parts of the country remote from ports of entry introduced forms may occur in abundance. Indeed, the figure of a "very common" New Zealand millipede given by Powell (1947: 42–3, Fig. 207) in his "*Native Animals of New Zealand*" appears to illustrate a European Iulid. A watch must be kept on the further spread of these and other overseas species, particularly with regard to their relation to our agricultural economy.

It remains for me, now, to express my thanks to Dr. Otto Schubart and Mr. J. Gordon Blower for help with identifications and literature, to Mr. Robert Brockie for specimens, and to Mrs. N. B. Causey, Dr. R. V. Chamberlin and Mr. S. W. Rolfe for literature.

References

Blower, G., 1953. On three species of *Cylindroiulus* Verhoeff (Diplopoda, Iulidae) in Britain. *Ann. Mag. nat. hist.*, (12) *6* (64): 305–16, 4 figs., 3 tables.

Causey, N. B., 1943. Studies on the life history and the ecology of the hothouse millipede, *Orthomorpha gracilis* (C. L. Koch 1847). *Amer. Midl. Nat., 29* (3): 670–82.

Chamberlin, R. V., 1920. The Myriapoda of the Australian region. *Bull. Mus. Comp. Zool. Harvard, 64* (1): 1–269.

Colenso, W., 1894. Description of a large species of *Iulus*. *Trans. N.Z. Inst., 26*: 106.

Conde, B., 1951. Un Pénicillate inédit de Nouvelle Zélande (Myriapodes Diplopodes). *Rec. Cant. Mus., 6* (1): 9–14, 5 figs.

Helson, G. A. H., 1955. Interception of potentially dangerous pests to New Zealand, 1950–55. *N.Z. Entomol., 1* (5): 5–9.

Holloway, B. A., 1956. Revision of the New Zealand Pill Millipedes (Oniscomorpha, Sphaerotheridae). *Trans. Roy. Soc. N.Z., 84* (2): 431–46, 5 figs.

Jacks, H., 1953–4. Plant Quarantine I. list of plant diseases and pests intercepted in New Zealand in 1951 . . . II . . . in 1952 . . . III . . . in 1953. *N.Z. J. Sci. Tech* (A) *35* (2): 169–71, (3): 273–5, (6): 555–7.

Powell, A. W. B., 1947. *Native Animals of New Zealand*. 96 pp. Unity Press, Auckland.

Rolfe, S. W., 1934. Notes on Diplopoda I. The re-study of a widely distributed British millipede, *Ophyiulus pilosus* (Newport). *Ann. Mag. nat. hist.*, (10) *14* (80): 192–203, 12 figs.

ROLFE, S. W., 1937. Notes on Diplopoda IV. The recognition of some millipedes of economic importance. *Journ. S.E. Agric. Coll. Wye,* 40: 99–107, 21 figs.

———— 1938. Notes on Diplopoda V. The recognition of some millipedes of economic importance—II. *Journ. S.E. Agric. Coll. Wye,* 42: 214–5, 5 figs.

SCHUBART, O., 1934. Tausendfüssler oder Myriapoda I: Diplopoda *Die Tierwelt Deutschlands, 28*: VIII + 1–318 pp, 480 figs.

Aphid Sampling

K. P. Lamb,

Plant Diseases Division, Department of Scientific and Industrial Research, Auckland.

[*Read as part of a symposium on Sampling of Insect Populations at the Annual Conference of The Entomological Society of New Zealand, May, 1958.*]

Of the numerous definitions of the term "population" we might consider briefly that of Pearl (1937): "*a population is a group of individuals set in a frame that is limited and defined in respect of both time and space*". This definition involves at least four separate ideas: number of individuals, kind of individuals, aliveness, and a framework in space and time. Recent ecological monographs consider the formal aspects of these concepts, but today I hope to illustrate some of them and their interactions in so far as they apply to a single group of insects: the family Aphididae.

Dr. Thompson* has already told us what he means by the term sampling, but before we go any further, let us consider some of the peculiarities of aphids as insects. First of all they are all obligate plant parasites of varying degrees of host specificity. They derive their food by sucking sap from plants and often from plants of a particular species, genus or family. Furthermore, in most cases, feeding and multiplication are confined to particular sites within the plant: whether on roots, stems or young, mature or senescent leaves and in a particular tissue within these organs. In some cases the preferred feeding site varies according to season or state of growth of the host plant.

Many aphids have complex life histories involving different forms (winged or wingless; sexual or parthenogenetic) and changing host preferences. Sexual forms of the black bean aphid are produced on spindle plants in autumn in Europe. The eggs overwinter and hatch in spring to give parthenogenetic forms whose progeny migrate to a variety of hosts including broad bean and sugar beet. Throughout the summer several generations of parthenogenetic females (including both winged and wingless forms) are produced on these alternate hosts until autumn, when sexuparae migrate back to spindle where sexual females are produced.

During the summer, aphids of this kind come to the notice of economic entomologists for two reasons. First of all their rapid

* Paper read as part of the same symposium.

parthenogenetic reproduction on suitable hosts results in the production of enormous populations which rapidly debilitate, damage or destroy the secondary host. When food becomes short, winged forms are produced and these fly off and eventually settle on another host plant to found a new colony. The second point of economic interest is that these winged forms are capable of transmitting plant virus diseases on their mouthparts or in their saliva, and, in fact, winged aphids are the main insect vectors of plant virus diseases.

The peculiar method of host selection by aphids favours virus spread even on plants which are not normal hosts to the aphids concerned. It appears that flying aphids land more or less at random on plants, have a brief test feed, then either stay and reproduce or fly off and try again on another plant. This test feed is often sufficient either to imbibe or deposit virus infected material.

Returning now to the question of population sampling, it should be obvious that our sampling design will depend upon the kind of information we want to get out of it—and there are many possible kinds.

Are we interested in a single aphid species or a single host species? Which form or forms of aphids concern us? Do we want to determine how much damage is being inflicted on a particular crop or host variety, or are we concerned with movement of winged aphids in connection with aphid dispersion or virus transmission? Or, are we interested in population growth in relation to climatic or nutritional factors? Or do we wish to assess some chemical or biological control measure? In each case a different sampling technique is indicated.

Our problem now is to determine how many aphids of a given kind occur in a given situation at a given time. Consider, for example, the case of a single aphid species infesting a single species of host plant in a field. We want to know how many aphids (irrespective of age and form) of this species occur on each plant at a given time. The only precisely accurate method would be to count every aphid on every plant. Since each plant may support up to 6–10,000 aphids on it, this would be an impossible task. Thus we must resort to some form of sampling. In other words we must invoke the aid of the statistician, one of whose principal objectives "is to draw inferences with respect to populations by the study of groups of individuals drawn at random that are referred to as samples" (Goulden, 1952).

There has been a great deal written about sampling, and it is a field with many pitfalls for the innocent and unwary. First of all our samples must be unbiased and truly representative of the population. At the same time we must make allowance for

sampling fluctuation which invariably occurs, and we should be able to measure this variability. Thus we have the dual problem of collecting appropriate samples and then of drawing valid conclusions from them. It is at this stage, the outset, that we should consult our biometrician in order to help us design a statistically acceptable sampling scheme.

Let us now consider some of the methods which have been used by aphid workers to collect and enumerate samples.

1. We have already indicated the difficulties of total enumeration, though this may sometimes be practicable.

2. Alternatively, whole plants may be taken at random from various parts of the field, placed in bags and taken to the laboratory. The aphids may then be washed off and:

(a) weighed, or

(b) suspended in liquid, thoroughly stirred and aliquots taken and counted, or

(c) determined volumetrically, or

(d) counted electronically,

3. Infestation may be assessed visually and given a rating of say 0 4 (0 being uninfested and 4 heavily infested). This method must be used with caution and unless properly applied it is open to large errors.

4. A combination of visual estimation and one of the other methods listed above. Thus, Banks (1957) classified bean plants in the field into 5 arbitrary classes of infestation. He removed 10 samples of each class to the laboratory and counted the number of aphids in each by a volumetric method. The mean number of aphids in each class was then multiplied by the number of plants in each class to give an estimate of the total population.

5. Instead of using the whole plant as a unit, many workers have counted aphids on parts—e.g., particular leaves, stems or branches.

(a) Maldwyn Davies (1934) took 100 potato leaves at random and counted the number of aphids present.

(b) Modifications of this method were used by Bald, Norris and Helson (1946). They counted adult and immature aphids on bottom, middle and top leaves of successive sample plants and also recorded the area of each leaf sampled. They used the ratio of nymphs to adults as a "multiplication index".

(c) Anscombe (1948) considered the statistical aspects of aphid population estimation on potatoes and discussed an unbiased method involving the count of aphids on every tenth leaf examined on a number of plants. He also discussed the 3-leaf method and inspection methods.

(d) Shands *et al.* (1954) described a more economical method using subunits of leaves as samples. Once again this was applied to the compound leaves of potato.

Apart from considering total aphid numbers per plant or per leaf, it is often instructive to have some measure of density, or in other words of the space-relative population.

Counts may be expressed in terms of unit leaf area or weight. Philosophical consideration of this brings us to questions of aphid physiology and behaviour. Thus Kennedy and his collaborators have clearly established that certain sites within the plant are preferred by particular aphid species or forms. In considering aphid density we should perhaps consider to what extent preferred sites are colonized and the distribution of such sites within the plant during its ontogeny. Recent work by Taylor (1955) on the development and aphid colonization of the potato plant shows much promise in that direction.

At this point we might stress once again that aphid counts are meaningless unless the physiology of the aphid and host are taken into account and unless we are quite clear in our own minds what we are investigating. Thus total counts of aphids on plants in mid-summer taken with a view to investigating host resistance to virus infection will be of little value if virus transmission occurred months before through the activity of alates of quite a different species which may not even have colonized the plants infected.

Movement and dispersion of aphids occurs primarily through the flight of winged forms. The work of C. G. Johnson and his school at Rothamsted has brought to light many interesting facts concerning aphid flight; particularly in relation to weather. By the use of ingenious suction traps, Johnson sampled the air continuously at various heights from ground level to 4,000 feet. He found that the number of insects flying depended upon both crop population level and flight activity. The number of aphids in the air varied according to season and even from hour to hour during the day. Further, he found that much aphid flight is passive, depending upon the velocity and direction of air currents. Ascending air currents waft aphids to considerable heights (up to 18,000 feet has been recorded). Also aphids may be blown hundreds of miles, yet still survive and reproduce. The longest hop recorded was 800 miles across the sea. The greater the altitude the sparser the aphid population according to a simple law. More than 70% of flying aphid populations are found at heights exceeding 1,000 feet above the ground.

The duration of flight of a single aphid may be about 2–3 hours. After a few days the flight muscles autolyse and flight is no

longer possible. Before final settling an aphid may have landed on and infested several plants with virus disease.

Other methods have also been used for trapping alates. Various types of sticky traps have been tried though these are not easy to handle and tend to be rather messy. A substantial advance came from the physiological studies of Moericke at Bonn. He studied the effect of various colours as landing stimuli for aphids. Yellow was highly effective so he designed a simple colour trap which has proved very effective for survey work. Such traps collect nearby winged aphids which are in the right behavioural state for normal landing.

We exposed eight of these traps in the field at Auckland for 12 months. Two types of yellow paint were used and every 2–3 days the traps were cleared and the aphids were counted and identified. During the year 4,272 aphids belonging to 39 species were collected and identified. That is to say, two-thirds of the total number of species known to occur in this country were collected in the 27 square feet of trap area. Almost 1,000 aphids per week were collected in the peak period, and in only two weeks of the year were no aphids trapped. The important virus vector, *Myzus persicae*, was trapped in 36 weeks of the year. This season was quite an average one so far as general aphid incidence on crops was concerned.

Some interesting facts are emerging from this work. For example, in the month of February approximately 800,000 winged aphids were landing per acre per week. Even in mid-winter some 12,000 aphids per acre per week were landing. Trap data lends itself to quantitative studies of aphid movement and it should be of value in field studies of virus spread.

Returning to our original definition of a population: we have discussed number and kind of individuals and their spatial distribution, so finally, a few words about distribution in time. Here we are in the classical field of population study—i.e., how populations change with time. Examination of recent reviews on this subject is rather an intimidating experience as one witnesses the vociferous proponents of one or another pet theory defending their last ditches. We are therefore compelled to look at the insects themselves for our answers.

Serial examination of aphid numbers on plants in the field soon brings home to us the plastic, rapidly changing state of aphid populations. Their rapid rate of young production rapidly brings about overlapping generations. Most species are found on parts of the plant exposed to the weather—and all sorts of climatic catastrophes can decimate aphid numbers. Rain and drought are perhaps the most serious, since the first washes aphids from the plant while the second often results in a failure of their food

supply. Natural enemies also take their toll; predatory syrphid larvae and ladybirds being most effective though parasitic Hymenoptera and fungus diseases account for many. Thus any deductions made from fluctuating aphid counts in the field must take into account relevant biological and climatic factors.

Another approach is to eliminate some of the interfering factors by culturing aphids under more or less controlled conditions in the insectary and then varying relevant factors at will. We have carried out some experiments of this sort, starting with one or a small number of aphids on a plant and then tracing the growth of the population with time. The mathematical description of this is formidable, nevertheless Dr. Darwin, of the Applied Mathematics Laboratory, has tested several aphid population growth models with encouraging results.

Ideally for population studies we require to construct "life tables" which give the probability of survival at any age and the fecundity at each age, assuming a stable age distribution. Few such life tables exist for insects, apart from stored products pests which are readily cultured, and with aphids we have the added complication of a constantly varying food supply. In view of my earlier remarks such results may well be remote from the situation in nature though they may open up new avenues of investigation for us.

Unfortunately equations describing population growth often contain several constants of little biological meaning—which reminds me of Claude Bernard's remark that with four constants you can draw an elephant: with five you can make it wave its trunk.

References

Anscombe, F. J., 1948. On estimating the population of aphids in a potato field. *Ann. appl. Biol. 35:* 567–571.

Bald, J. G., Norris, D. O. and Helson, G. A. H., 1946. Transmission of potato virus diseases. 5. Aphid populations, resistance and tolerance of potato varieties to leaf roll. *C.S.I.R. Bull. no. 196.*

Banks, C. J., 1954. A method for estimating populations and counting large numbers of *Aphis fabae* Scop. *Bull. ent. Res. 45*: 751–756.

Davies, W. M., 1934. Studies of aphides infesting the potato crop. 11. Aphis survey: its bearing upon the selection of districts for seed potato production. *Ann. appl. Biol. 21*: 283–299.

Goulden, C. H., 1952. *Methods of statistical analysis.* 2nd ed. John Wiley, N.Y.

Pearl, R., 1937. On biological principles affecting populations: human and otherwise. *Am. Nat. 71*: 50–68.

Shands, W. A., Simpson, G. W. and Reed, L. B., 1954. Subunits of sample for estimating aphid abundance on potatoes. *J. Econ. Ent. 47*: 1024–1027.

Taylor, C. E., 1955. Growth of the potato plant and aphid colonization. *Ann. appl. Biol. 43*: 151–156.

Notes on Insect Pests, 1957-58

By K. A. J. Wise,

Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

LEPIDOPTERA

Lithocolletis messaniella Zell. (Gracillariidae)

During a short survey of the oak leaf-miner position in April, 1957, the following food-plants were found for the first time.

Family Platanaceae

Platanus sp. (Plane)

In Hastings mines were found in several leaves on one branch of one tree which was amongst many other plane trees in a park. Most mines were small but three were tentiform and from one of these the adult had apparently emerged. At all other times planes have been found to be immune from attack.

Family Ulmaceae

Ulmus sp. (Elm)

Mines, from some of which adults had emerged, were found on several trees in Palmerston North.

Family Rosaceae

Prunus persica Sieb. and Zucc. (Ornamental Peach)

One typical mine, with empty pupal exuvium, was found in Palmerston North.

Other new records are as follows:—

Family Fagaceae

Quercus alnifolia Poech.

Mined leaves with empty exuviae were collected by the author from one tree in Hastings in February, 1953.

Quercus incana Roxbg.

Mined leaves of this evergreen oak were collected by W. Marshall, in Christchurch, in January, 1958.

Family Hamamelidaceae

Loropetalum chinense Oliv.

Mr. B. B. Given, Entomology Division, Nelson, has observed mines in plants of this shrub in January, 1957, and April, 1958, in Nelson.

Mr. Given has kindly supplied mined specimens and the records of the last two species above.

Spilonota macropetana Meyr. (Olethreutidae)

Larvae of the Eucalyptus leaf-roller damaged seedling Eucalyptus in a nursery at Hamilton, April 16, 1957 (Agriculture Department). Similar damage occurred at Cambridge in December, 1956 (Agriculture Department).

Mecyna maorialis (Feld.) (Geometridae)

Caterpillars which had migrated from infested stands of lupins, fed on and damaged foliage and flowers of chrysanthemums (*Chrysanthemum* sp. cult.) at Haumoana (Hawke Bay), March 26, 1957 (Agriculture Department).

Heliothis armigera (Hbn.) (Noctuidae)

Two new food plants are recorded for this species. Larvae were feeding on a crop of peanuts (*Arachis hypogaea* L.) at New Plymouth, March 6, 1957 (Agriculture Department). Several species of Eucalyptus seedlings (including *E. ficifolia* F. v. M.) were damaged at Hamilton, April 16, 1957 (Agriculture Department).

Achaea janata (L.) (Noctuidae)

Caterpillars of this immigrant species were again present on castor oil plants in Gisborne, April 15, 1958 (Agriculture Department) and were found for the first time in Auckland, April 14, 1958 (Agriculture Department).

Barea confusella Walk. (Oecophoridae)

In Hawke Bay, larvae of this Australian species were found boring in the bark of poplar trees (*Populus* sp.), October 21, 1957 (Agriculture Department).

COLEOPTERA

Clivina rugithorax Putz. (Carabidae)

Beetles were numerous in holes in potato tubers (*Solanum tuberosum* L.) at Otorohanga, February 13, 1958 (Agriculture Department).

Otiorhynchus rugostriatus Goeze (Curculionidae)

This, the rough strawberry weevil, and the following species, are pests of strawberries overseas. Adults of both species have been taken in New Zealand, usually in houses and sometimes in large numbers. However, no instance of damage to strawberries has yet been ascribed to either species.

Adults were taken in a house in Masterton, March, 1958 (Mrs. F. Callister coll.), and in Papatoetoe, April 11, 1958 (G. V. Cronin coll.).

Otiorhynchus ovatus (L.) (Curculionidae)

Adults of the strawberry root weevil were found in a house in Christchurch, February 13, 1958 (Agriculture Department).

Acantholybas brunneus Bredd. (Coreidae)

Nymphs were again taken on rhubarb in Auckland, March 11, 1958 (R. G. Hunkin coll.), March 5, 1958 (W. Todd coll.). In captivity some of them fed on rhubarb and some on French bean pods. On the latter they passed through two or three stages to become adults.

Calocoris norvegicus (Gmel.) (Miridae)

The potato capsid was abundant on potatoes, (*Solanum tuberosum* L.) and broad beans (*Vicia faba* L.) and was also found on lettuces (*Lactuca sativa* L.), peas (*Pisum sativum* L.), silver beet (*Beta vulgaris* L. var. *cicla* Moq.), rhubarb (*Rheum rhaponticum* L.), turnips (*Brassica campestris* L. var. *rapa* (L.)), and dahlias (*Dahlia* sp. cult.), in an Invercargill garden, January 13, 1958 (Agriculture Department).

Arocatus rusticus Stal (Lygaeidae)

Numbers were found on a plant of *Oxypetalum caeruleum* Decne (Syn. *Tweedia caeruleum*) at Maungatapu, Tauranga, April 14, 1958 (Agriculture Department).

An Aberration in *Baeocera scutellaris* (Redt.) (Coleoptera : Scaphidiidae)

By (Mrs.) Brenda M. May,

Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

In the course of work on the Coleoptera collection of the Plant Diseases Division a specimen of *Baeocera scutellaris* (Redt., 1867) collected at Owairaka, Auckland, on January 6, 1949, by J. S. Edwards, was found to possess an unusual aberration of one elytron.

This note is written with the object of placing this unusual form on record, and of drawing attention to an inaccuracy in the description of the species.

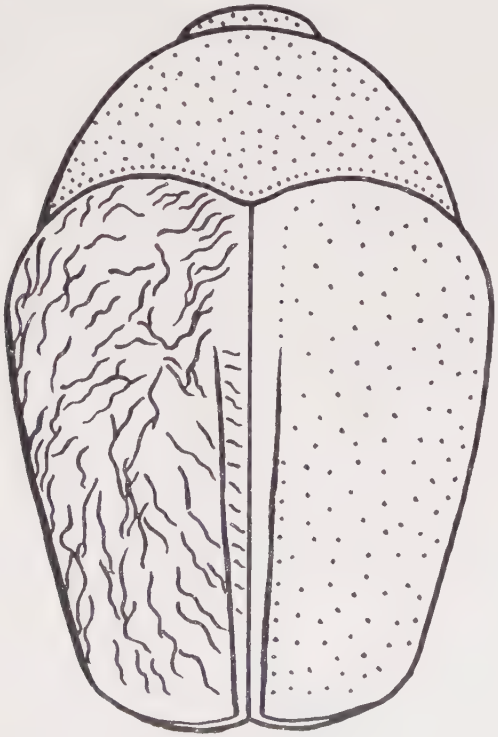


Fig. 1.—Head, pronotum and elytra of aberrant specimen of *Baeocera scutellaris* (Redt.) (× 38).

The elytral characters for the genus, according to Seidlitz (1891) in his key to the Scaphidiidae, are "Flügeldecken verworren punktirt" (Couplet 1') and "Der Nahtstreifen der Flügeldecken bis vorn deutlich, von der Naht weit abstehend" (Couplet 3_1). Redtenbacher (1867) as quoted by Broun (1880) described the elytra of *Scaphisoma scutellare* as "Elytris impunctatis, stria suturali postice profunda, ante medium obsoleta impressa". Although Redtenbacher stated that the elytra were impunctate, very fine scattered punctures containing minute setae were seen on head, pronotum, and elytra of forty-three normal specimens examined. This is in accord with the presence of this character in the genus, as given by Seidlitz.

On the abnormal specimen from Owairaka, the left elytron, while showing the sutural stria, is extremely rugose over the whole surface. At the apex and along the suture the wrinkles are much less obvious. The rugosity does not appear to follow any particular pattern and no punctation is visible (see Fig. 1). Both elytra are normal in size and shape, and in all other respects the beetle conforms to the species description.

References

Redtenbacher, L. 1867. *Reise Novara, 2,* p. 32, cited in Broun, T., 1880. *Manual of the New Zealand Coleoptera, 1,* p. 159.

Seidlitz, G., 1891. *Fauna Baltica, 2 Aufl.,* p. 72–3.

Original Material of the Ant *Discothyrea antarctica* Emery, 1894, in New Zealand

R. W. Taylor,

Zoology Department, University of Auckland.

Recent examination by the author of the ant material from the Brooke's Collection at Plant Diseases Division, Auckland, has resulted in the discovery of three worker specimens of the native ant *Discothyrea antarctica* Emery, which are very probably part of the original series of this species. The data attached to these specimens, which are mounted on a single card, is in the handwriting of the late Major Thomas Broun, and reads as follows:—

Hunua, 26-12-91: n. gen. near *Syscia*: No. 8. Smith sent April '91.

In his description of *Discothyrea antarctica,* Emery (1894) stated that the type series, also of three specimens, had been sent to him by Mr. W. W. Smith, and was collected by Captain Broun, in the Hunua Range, on January 26, 1891.

The data on the Brooke's collection specimens therefore, except for the discrepancy in the month of collection, showed that they were possibly part of the original series, which had been retained by Broun. In order to clear up this matter Dr. Delfa Guiglia, of the Museo Civico Di Storia Naturale, Genoa, very kindly checked the labels on the types of this species, in the Emery Collection, and established that the date cited is indeed December 26, 1891, and not January 26, 1891, as stated by Emery.

In the light of these findings the Plant Diseases Division specimens are almost certainly part of the original material and, therefore, are the most authentic examples of the species in the country.

The author wishes to thank the Director of the Plant Diseases Division for allowing the use of these specimens. Thanks are also extended to Dr. Guiglia for her very kind co-operation.

Reference

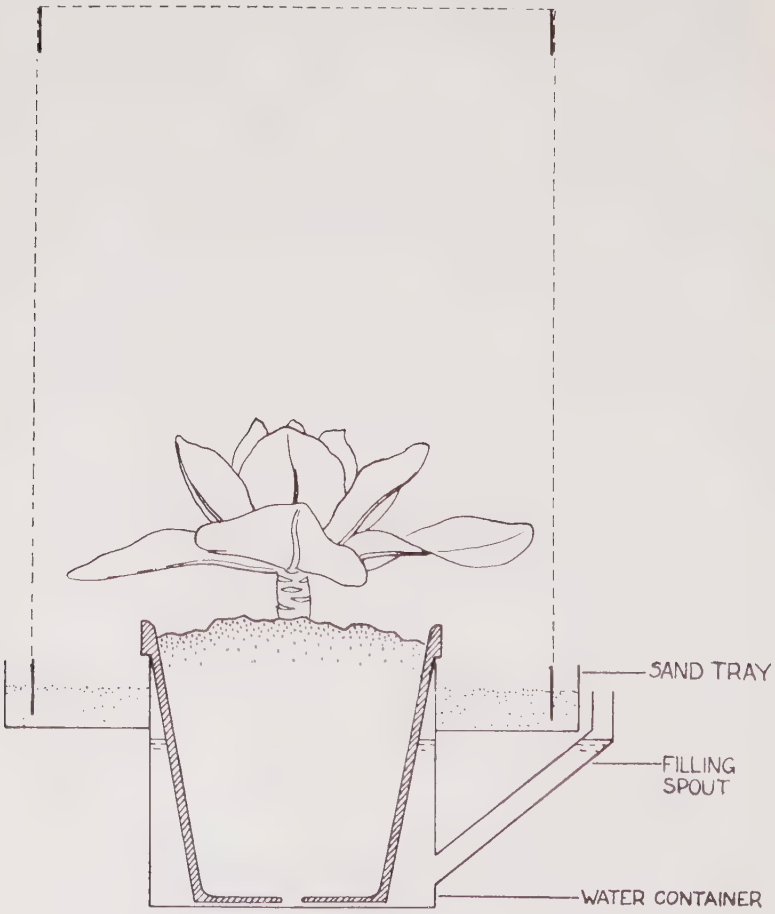
Emery, C., 1894. On a New Species of Ant from New Zealand. *Trans. proc. N.Z. Inst.* 27; 635–636 (p. 636).

A Container for Rearing Insects on Potted Plants

B. B. Given,

Entomology Division, Department of Scientific and Industrial Research, Nelson.

The container illustrated has been in use at the Nelson laboratories of the Entomology Division, Department of Scientific and Industrial Research, for a number of years, and has proved very satisfactory. Size is not mentioned, as this will naturally be governed by the size of pot and plant to be accommodated.



The water container, sand tray and filling spout are of heavy galvanized iron. The water container is constructed to fit neatly beneath the pot collar and the filling spout, which is of about one inch diameter, must be long enough to allow the almost complete filling of the pot container, but not long enough to make overflowing into the sand tray possible. The sand tray is in the form of a circular collar around the water container. This collar gives a convenient sand seal with the cage base.

Cage construction can be of any type which provides a deep enough lower metal ring to give a good seal with the sand tray.

The principal advantages of this type of container are portability, compactness and convenience of bottom watering without cage disturbance.

Aphid Populations: Ecology and Methods of Sampling Aphids *Myzus persicae* (Sulz.) and *Aulacorthum solani* (Kltb.)

By G. A. H. Helson,

Department of Agriculture, Wellington

[*Read at the Annual Conference of the Entomological Society of New Zealand, May, 1958.*]

Ecological studies on the transmission of potato virus diseases, and leaf roll in particular, by the aphid *Myzus persicae* (Sulz.) and *Aulacorthum solani* (Kltb.) were made at Canberra A.C.T., Australia, between the years 1941 and 1948. In order to study the comparative intensity of the aphid population it was necessary to develop simple techniques for use in field and experimental plots which would be applicable under field conditions and yet yield results statistically comparable.

1. *Habits of the Aphid Vectors*

For this purpose the habits and feeding sites of the two species concerned, and particularly that of the principal vector, *Myzus persicae,* were studied.

M. persicae overwinters in Canberra in two forms. In the first form overwintering eggs are laid in the autumn on peaches and nectarines (*Prunus persica* Stokes var.). These eggs hatch and give rise to a generation of winged, viviparous females which migrate to potatoes in late October or early November. From these apterous, parthenogenetic generations are produced. The second form is as viviparous, parthenogenetic females slowly reproducing all winter on brassica crops. An alate, parthenogenetic generation appears in spring, and this migrates to potatoes and other summer host plants to give birth to a series of apterous, parthenogenetic summer generations.

A. solani overwinters on sowthistle (*Sonchus oleraceus*), and dock (*Rumex* spp.) as parthenogenetic females slowly breeding all winter. In spring alatae appear and migrate to summer host plants, including potato, to give birth to apterous and parthenogenetic summer generations.

2. *Seasonal Cycle*

The aphid population increases from spring to summer, and with the onset of hot, dry summer weather it disappears from the potato crop from late December to the end of January. It reappears in February and increases to an autumn maximum in

March and early April, by which time light frosts have commenced and the winter migration begun, thus completing the seasonal cycle.

3. *Distribution on the Plant*

During the spring and summer each species exhibits a particular distribution on the potato plant governed by the most favoured feeding site of the species.

M. persicae is almost invariably found on the under surface of leaves on the middle and upper portions of the plant with a preference for the young leaves at the growing tip.

A. solani, on the other hand, prefers to feed on the under surface of leaves on the lower half of the plant from the middle down to the bottom leaf. After severe rain storms it was observed that large numbers of this species, which is larger than *M. persicae*, were shaken off the plant on to the ground beneath. More appeared to be shaken from the middle of the plant than from the bottom leaves, and preference for the lower portion of the plant may, therefore, be partly governed by protection afforded from the sun, wind and rain. Aphids so shaken off were observed to climb back on to the plant with the return of favourable conditions. Storms did not appear to affect the smaller *M. persicae* to nearly the same extent.

This study of the habits of the aphids showed that the distribution of the insects, as vectors of the virus diseases of potatoes, was much more complex than distribution of such other active insect vectors as thrips or jassids. Where there are no gradients, such as those caused by a prevailing wind, these active forms are likely to be distributed at random on plants (Bald, unpublished data), and if their numbers are arranged in a frequency series this will be found to approximate to a Poisson series.

Aphid populations, on the other hand, are not nearly so active, and if counts are made at the initial stage when the migrant, winged forms are depositing nymphs on potato plants, these are found to give a frequency series in accord with the Poisson distribution. (Bald, Norris and Helson, 1950, Table 1.)

However, where the area of the crop is great enough, or other factors like that of prevailing wind occur, or if individual plants differ in their attractiveness to the aphids because of their age or physiological condition (Bald, Norris and Helson, 1946) then a gradient of the initial invading population is induced. This later becomes dissipated with the rapid multiplication and subsequent dispersal of both alate and apterous adults. The population then exhibits a non-random distribution (Bald and Norris, 1943).

Thus the habits of the two species determine when field recording begins in the spring, and their peculiar distribution on different parts of the plants determines the methods of field sampling.

4. *Methods of Sampling*

Sampling of potato fields for aphids began in the spring at a time determined by the first appearance of alate, migrating females caught in a pair of slowly rotating nets, which constantly sieved the air adjacent to the experimental plots at a height of 3ft; or on the first observed appearance of winged females in field crops. This usually took place in October or early November.

Based on a study of the habits of the aphids, counts were made by a modification of the Davies (1934) technique in which he sampled 100 potato leaves at random in the field. The refinement in sampling consisted of collecting 50 leaves on each diagonal traverse of the field, taking leaves from the top, middle and bottom of the plants in turn. In this way 100 leaves were taken from the field from all parts of the plants where both species were to be found. A further refinement, where internal statistical data were required, was to break each diagonal traverse into two sections, and record counts taken from 25 leaves from each half of the full traverse.

In addition to recording the total number of species concerned, field records were made of the numbers of alate, apterous and nymphal forms of each species present at each recording. Recordings were made at weekly intervals on experimental plots, and field identifications of each species were made on the spot, where time permitted this to be done.

5. *Apparatus Used for Sampling*

In district field surveys where field identification and recording could not be carried out on the spot because of the need for speed in making the field surveys, the apparatus used for sampling populations was a modification of that used for sampling pea aphid populations developed and used by Gray and Schuh (1941, p. 413, Fig. 2). In this case the sampler was half the diameter and $4\frac{1}{2}$ inches shorter than the apparatus used by Gray and Schuh, and the pillbox at the neck of the internal funnel replaced by a screw-on brass box which was more robust than the cardboard pillbox. As the leaves were plucked in the field they were placed over the funnel in the sampler and the lid replaced. Cotton wool in the gas chamber of the lid was previously moistened with methyl-isobutyl-ketone, and this filled the body of the cylinder. Methyl-isobutyl-ketone causes all the aphids to withdraw their mouthparts and drop off the leaves. Even first instar nymphs withdrew their stylets. Anaesthesia occurred in about ten minutes, at the end of which time the sampler was shaken fifty times up and down by the side handles until all the aphids had fallen through the screen in the pillbox below. When all the aphids had been so collected the pillbox was removed and the aphids preserved in 70 per cent. alcohol for future laboratory recording.

By this means two or more persons could sample the same area and obtain equivalent results which were statistically comparable.

References

Bald, J. G. and Norris, D. O., 1943. Transmission of Potato Virus Diseases 1. Field experiment with leaf roll at Canberra, 1940–41. *Bull. Coun. sci. indust. Res. Aust.* 163: 1–18.

Bald, J. G., Norris, D. O., and Helson, G. A. H., 1946. Transmission of Potato Virus Diseases 5. Aphid population, resistance and tolerance of potato varieties to leaf roll. *Bull. Coun. sci. indust. Res. Aust.* 196.

——— 1950. Transmission of Potato Virus Diseases VI. The distribution of the aphid vector on sampled leaves and shoots. *Aust. J. agric. Res.* 1 (1): 18–32.

Davies, W. M., 1945. Studies on aphides infecting the potato crop II. Aphis survey: its bearing upon the selection of districts for seed production. *Ann. appl. Biol.* 21: 283–98.

Gray, K. W. and Schuh, J., 1941. A Method and Contrivance for Sampling Pea Aphid Populations. *J. econ. Ent.* 34 (3): 411–415.

Structural Characters of the Larva of *Selidosema suavis* (Butler) (Lepidoptera : Geometridae. Subfamily Ennominae)

By J. S. Dugdale,

N.Z. Forest Service, Forest Research Institute, Rotorua.

This paper, first of a series on larvae of defoliating insects, deals with external characters of *Selidosema suavis* (Butler), a lepidopterous defoliator which is common on exotic conifer species grown in this country. The characters are given by instars, and an attempt is made to show how the setal pattern changes during larval development. This setal pattern is, so far as is known, characteristic of this species. Lists of host plants and localities (private plantations and State exotic forests) are given.

Introduction

Descriptive work on the larvae of New Zealand Lepidoptera has been carried out principally by Hudson (1928, 1939, 1950), Watt (1920, 1921) and Chappell (1929). Though certain larvae of the Tortricidae and Carposinidae of economic importance have been fully described by Clark (1936), Dumbleton (1932) and Jeffreys (1939), no adequate structural descriptions have been produced of the species of the subfamily Ennominae.

The classification adopted here is that used by Brues *et al.* (1954), pp. 237–238. The Ennominae include the Boarmiinae. The taxonomy is:

Super Family GEOMETROIDEA

Family GEOMETRIDAE

Subfamily Ennominae

The adult characters delimiting the Ennominae are:

"Hindwing with vein M_2 very weak or absent (present in *Abraxas*), Sc entirely free from R or only shortly anastomosed at base, and the two veins not bridged by a cross vein; radial cell rarely present; hind tibiae usually with hair pencil, lying in tibial groove; male antennae usually pectinate (rarely females); male hindwing often with blister-like fovea near anal vein, forming concavity on underside; often stout hairy moths. Cosmopolitan." (Brues *et al.*, 1954). The Ennominae include such conifer defoliators as *Bupalus piniarius* Linn., and *Semiothisa liturga* (Hbn. in Europe and *Lambdina fiscellaria lugubrosa* Hulst. in North America. In the New Zealand Ennominae, of the 35 species of *Selidosema* (Hubner) present, six are known defoliators on exotic conifers growing in this country, and of the 12 species of *Declana* Walk., two are defoliators on these same host plants, as is *Hybernia*

indocilis Meyr. The species of other genera (*Azelina* Guen., *Gargaphia* Walk. and *Sevora* Walk. have various species of ferns as host plants.

Hudson and Chappell have described the larvae of sixteen species of the genus *Selidosema*, but the descriptions and illustrations are lacking in structural detail, too much reliance being placed on characters such as colour or pattern. A series of papers is planned, dealing with the larvae of the genus *Selidosema* defoliating forest trees in New Zealand, of which this, the first part, deals with *Selidosema suavis* (Butl.).

As a defoliator, this species is of importance in silviculture. It has twice reached epidemic proportions (in 1951-52 at Eyrewell and Balmoral Forests, Canterbury, and again in 1957 at Eyrewell Forest) and is the most often found Ennomine looper in exotic plantations in New Zealand. It is distributed from North Auckland to Stewart Island, and from sea level to 3,000ft wherever there are *Nothofagus* species, exotic conifers, or native podocarps. The larva of this species varies so much in colour that it would be useless to describe all the colour varieties known. The structural characters are more dependable.

Material

This work was done using material made available from the routine collections sent in by the forest biology observers of the New Zealand Forest Service. The larvae were preserved in Andre's fluid (for setal and head capsule studies), or examined alive (for colour and pattern).

The setal terminology is that advanced by Hinton (1946), while the crotchet terminology is that of Peterson (1948).

Description of the Larva

1. *Chaetotaxy.*

Instar 1 (Fig. 1A).

Total length: 2 mm (newly hatched) to 5 mm.

The head capsule is rounded in lateral profile, and no genal angle is evident between setae L1 and P1, and there is no conspicuous concavity appearing on the face. The chaetotaxy of the head capsule appears incomplete, the following setae and punctures being minute: setae G, X, and punctures Pa, Aa, Adfa, and Xa. All setae are shorter than the antennae, and laterally placed setae (L1, 01 and 03) are twice as long as other setae. The head capsule has the frontal and adfrontal area closed. The 6 ocelli are arranged as shown in Fig. 6, with Ocellus 3 twice as large as the others. Each antenna is armed on the penultimate segment with a seta which is 1⅓ times the length of the antenna. The protergal plate (cervical shield or prothoracic shield) is split widely down the dorsum into two halves, and is centrally placed with

reference to the anterior and posterior margins of the segment. On the anterior margin are setae XD1 and XD2, and on the posterior margin setae D1 and D2, while the ventral angle abuts on the slanting pinaculum of the bisetose SD group. The lateral group is bisetose (L1 and L2) and is anterior to the spiracle. The supraventral group (SV_1, SV_2) is also bisetose, the pinaculum being horizontal. In each of these three bisetose groups (SD, L and SV) one seta is long and thin, while the other is approximately 1/3 its length and stout. The ventral seta, V1, and the proprioceptors (MXD1, MV 2 and 3) are typical in position. Both the mesothoracic and metathoracic segments have dorsal proprioceptors, in line with D2. As in the prothorax, SD1 is the longest seta. The lateral group is unisetose and is nearer the anterior margin in the metathorax than in the mesothorax. The SV group is also unisetose, only the hind seta being present (SV_2).

The abdominal segments bear only the proprioceptors MD1 and MV3, neither untypical in position. The tactile setae always present are D1 and D2, SD1, L1 and SV1.

Prolegs are present only on segments 6 and 10. No rosette of setae, nor any other indication of an incipient proleg is present on segment 5 of the abdomen. The supraventral group of setae is bisetose in all segments except segments 1, 2, 7–9 where it is unisetose.

Instar 2 (Fig. 1E).

The head capsule is not changed in shape, and its chaetotaxy is also unchanged. On the abdomen, the SV group has three strong setae on all segments except on segment 8, where SV is bisetose, and segment 6, where the proleg has four SV setae. Present also are three extremely small setae, the precursors of the extra SV setae in instar three. The dorsal setae are tuberculate on segment 8.

Instar 3 (Fig. 1B).

The head capsule is cheeked, but the chaetotaxy is unchanged. The setae on the rest of the body are now sharply divided into dorsal setae (groups D, SD and L), which are short and dark, or black; and ventral setae (groups SV and V), which are short and pale. Secondary setae make their appearance in this instar, the L group of the mesothoracic and metathoracic segments being supplemented by two new setae, one immediately ventral to the primary setae, the other posterior to it. The first abdominal segment has two SV setae ventral and anterior to the primary SV seta and another slightly ventral and posterior to it. The other segments of the abdomen show an elaboration of the supra-ventral group not equalled by any other of the seven species of this genus so far examined. The rudimentary setae present in instar 2 are now fully developed.

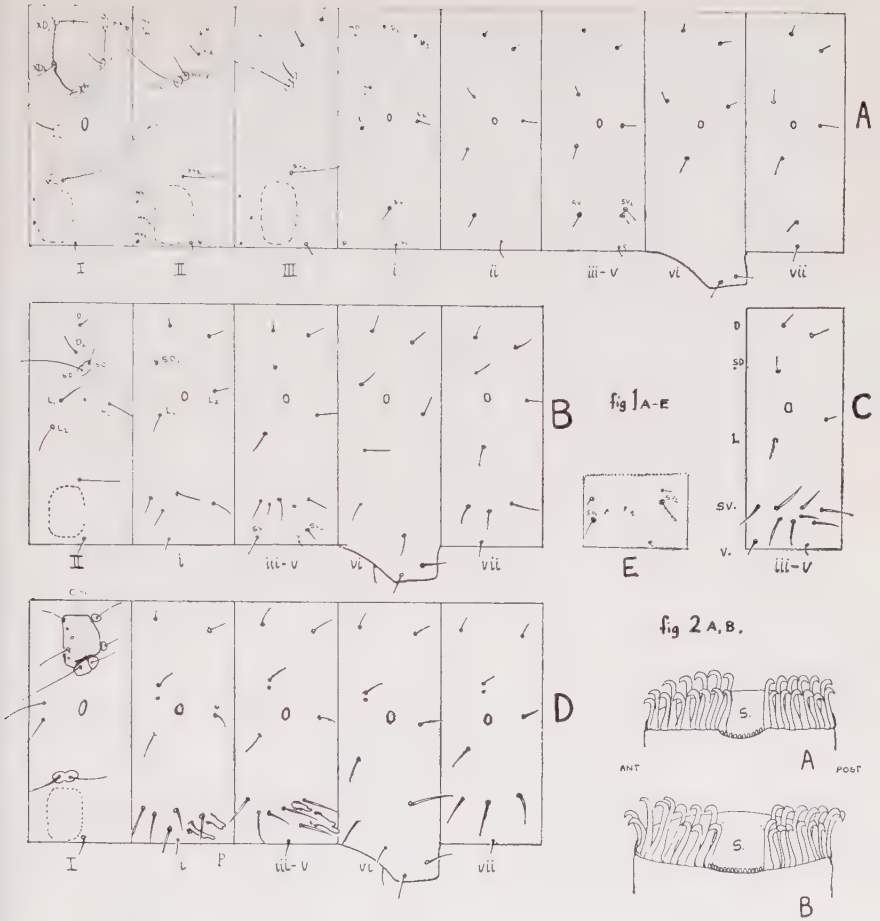


FIG. 1 (Larval chaetotaxy). Diagrammatic.—A: 1st instar. Thoracic segments and abdominal segs. 1–7. B: 3rd instar. Mesothorax and abdominal segs. 1, 3–7. C: 4th instar. Abdominal segs. 3–5. D: 5th instar. Prothorax, and abdominal segs. 1, 3–7. E: 2nd instar. Supraventral and ventral portion of segs. 3–5.

FIG. 2.—A and B: 6th and 10th abdominal seg. prolegs of 5th instar larva, both in mesal view.

EXPLANATION OF ABBREVIATION IN FIGURES

a.s., anal shield; c.s., cervical shield; Notch, the nick present in the lateral posterior margin of the epicranium; p., abdominal papillae; pp, paraproct. s, spatula of proleg. Setae—A, antennal setae (head capsule); O, ocellar setae (head capsule); SO, subocellar setae (head capsule); L, lateral setae (both head capsule + body); P, posterior setae on upper epicranium; D, dorsal setae (body); SD, subdorsal setae (body); SV, supraventral setae (body); V, ventral setae (body); MD, dorsal proprioceptors; MV, ventral proprioceptors.

Instar 4 (Fig. 1C).

The head capsule has the epicranium cheeked and the cheek margin extends between setae L1 and P1 to the ocellar angle. The cheek includes the ocelli and setae P2, L1, A2, O1, O2 and O3. No changes in the chaetotaxy of the head, thoracic segments, or abdominal segment 1 are evident. The SV group on the abdominal segments 2–5 is further elaborated by development of the new members, segment 2 now bearing five setae, and the other segments five or eight setae in this group. The setae point laterally and are thick and pallid.

Instar 5 (Fig. 1D). Total length, 22–27 mm.

The first abdominal segment has an elaborate SV group. Papillae may or may not appear. When present, they are simple or, if branched, then the branches are small and simple: the papillae are rarely longer than the setae in the complex SV groups on the abdominal segments. Papillae are present in the posterior half of the segment, amongst the posterior SV members. There is always a pair of tubercles on the dorsum of the eighth abdominal segment, situated dorsal and caudal of seta D2. More often than not, there is a similar pair of tubercles on segment 4, in the same position relative to the D setae. Neither pair of tubercles is setose.

In all instars the first abdominal segment is as long as the 2nd and 3rd thoracic segments combined.

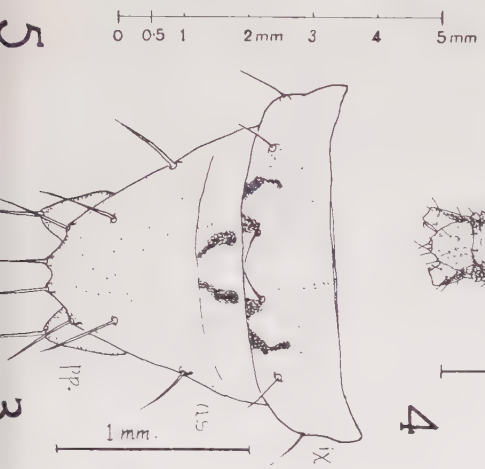
2. *Other Structures.*

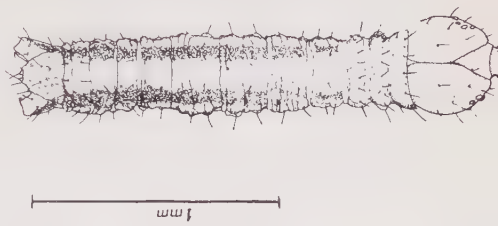
The form, though not the number, of components of the crotchet arrangement is constant from the first to the last instar. This arrangement (Fig. 2 A, B) is a uniserial, tri-ordinal heteroideous mesoseries, arranged in a slightly curved line. There are two outer sections and an inner section. The inner section, over which the bulbous spatula expands, is comprised of stumps, while the flanking outer sections are biordinal. The number of crotchets in each proleg is as follows:

	Proleg seg.	Anterior-	Mid-	Posterior-Section
1st-2nd Instar	vi:	6	6–7	5
	x:	6	10–15	5–6
3rd to last Instar	vi:	12	8	14
	x:	12	16	12

The spiracles are inconspicuous in all instars. The largest are the prothoracic pair and the 8th abdominal segment pair; as is usual, the latter is situated on a line above the other spiracles. At no time are they as conspicuous as in *Selidosema panagrata* (Walk.).

The anal shield (Fig. 3) (suranal plate) is broader than long in the early instars, lengthening until it is as long as broad in the last instar. A deep basal furrow extends transversely across the





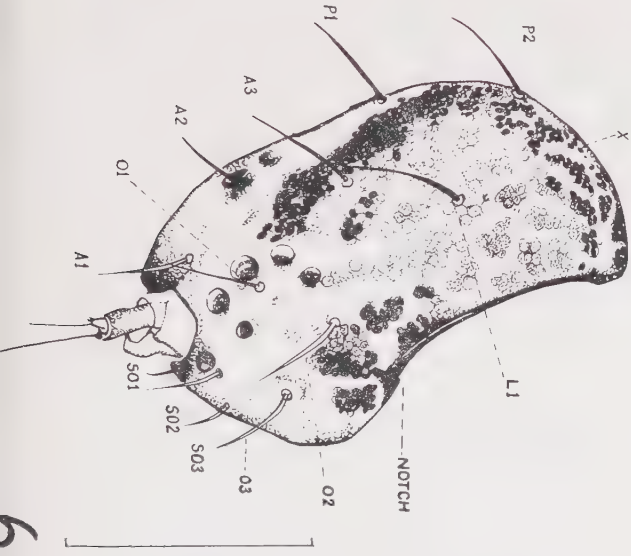


Fig. 3. –9th abdominal segment and anal shield of 5th instar larva, dorsal view.

Fig. 4.—1st instar larvae, just hatched, dorsal view, showing colour pattern.

Fig. 5.—3rd instar larva, dorsal view, showing colour pattern.

Fig. 6. –Head capsule of fifth instar larva, lateral view, showing chaetotaxy, ocellar arrangement and colour pattern

whole of the tenth segment and delimits the anterior edge of the shield.

The hypoproct and the two paraprocts are not greatly produced, the paraprocts being pyramidal, each with a long apical seta. The thin, acute hypoproct is hidden under the shield.

The larva is cylindrical in the first to third instars but shows a tendency to flatten during the fourth to last instars. The first to third-instar larvae rest with the body making an angle of 45° with the twig, leaf or needle, while the later instar larvae lie flat along it.

3. *Colour Pattern of Live Larvae.* (Figs. 4, 5, 6.)

The first-instar larva is pale green with a dark brown supralateral stripe extending from the thorax to the anal shield. The head capsule is light brown, and is held obliquely. The second instar larva bears the same pattern, sometimes with two dark blotches on the dorsum of segment 5. The ocelli are all margined in this instar. The third instar is a darker green, or brown-green, with the supralateral bands still present. The dark blotches on segment 5 persist, and further pairs of blotches appear on the dorsa of segments 2, 3 and 4. There is a great variation in the number and intensity of these blotch pairs. The head capsule is fox red. In some larvae the supralateral bands are broad, giving the larva a black appearance from above. The fourth instar displays a transition stage between the pattern of the 3rd instar and that of the last instar. The head capsule is dappled in brown and grey, or is fox red, and is held more or less perpendicularly when at rest. On the body, the supralateral line is broken intersegmentally, and the body is bright green, or dull brown. The dorsal line is often present as a conspicuous broken white line. The blotches are now formed into chevrons, which in the later instars form part of the diamond pattern typical of this species. The venter is pale green with a central dark triangle on each segment.

The fifth instar has the body outline broken by the simple papillae and thick white setae of the supraventral group. The usual pattern, basically a line of diamond shapes along the dorsum expanding on to the subdorsum, is in many cases absent, the larva being pale green with lateral stripes of white or buff, or yellowish green. The venter is pale blue-green. In all cases the pairs of tubercles present on segments 4 and 8 are black or dark brown. The head capsule (Fig. 6) is brown or grey, dappled and darker along the cheeks. Larvae have been noted that were practically black, even the venter being slate in colour. In all cases the dark triangle on the ventral midline on each abdominal segment is discernible. No constant local differences in larvae were observed.

4. *Distribution.*

This species has been collected from exotic conifers in the following State and private forests:

North Island. Waitangi S.F.; Omahuta S.F.; Puhipuhi S.F.; Glenbervie S.F.; Nukuroa S.F.; Woodhill S.F.; Waiuku S.F.; Maramarua S.F.; Whangapoua S.F.; Rotoehu S.F.; Kaingaroa S.F.; Whakarewarewa S.F.; N.Z. Forest Products, Maraetai; Esk S.F.; Gwavas S.F.; Erua S.F.; Karioi S.F.; Ngaumu S.F.; Waitarere S.F.; Santoft S.F.; N.Z. Forest Service Nursery, Bulls; plantations and shelterbelts at Wellington, Masterton, Marton, Lower Hutt, New Plymouth and Matakana Island.

South Island. Rai Valley S.F.; Golden Downs S.F.; Dumgree S.F.; Tawhai S.F.; Granville S.F.; Hanmer S.F.; Evrewell S.F.; Ashley S.F.; Balmoral S.F.; Raincliff S.F. (Waimate); Berwick S.F.; Tapanui S.F.; Conical Hills S.F.; shelter belt at Lake Wanaka; Woodlaw S.F.; Herbert S.F.; Pebbly Hills S.F.; Jubilee Hill S.F.; Dusky S.F.; Beaumont S.F.; plantations at Dunedin and Christchurch.

5. *Host Plants (1) Indigenous*[1].

Metrosideros perforata (Forst.) A. Rich. (Hudson, 1928)
Metrosideros robusta A. Cunn. (Hudson, 1928)
Leptospermum ericoides A. Rich. (F.R.I. records)
Leptospermum scoparium Forst. (F.R.I. records)
Nothofagus menziesii (Hook. f.) Oerst. (F.R.I. records)
Nothofagus fusca (Hook. f.) Oerst. (F.R.I. records)
Nothofagus cliffortioides (Hook. f.) Oerst. (F.R.I. records)
**Nothofagus solandri* (Hook. f.) Oerst. (F.R.I. records)
Griselinia littoralis Raoul (F.R.I. records)
Beilschmiedia tawa Benth. & Hook. (Forst. f.) (Hudson, 1928)
Leucopogon fasciculatus (Forst. f.) (Hudson, 1928)
Podocarpus dacrydioides A. Rich. (Hudson, 1939)
Podocarpus spicatus R. Br. (Hudson, 1939)
Podocarpus ferrugineus D. Don (F.R.I. records)
Phyllocladus alpinus Hook. f. (Hudson, 1950)
Phyllocladus trichomanoides D. Don (F.R.I. records)

(2) Exotic[2]

Nothofagus procera Oerst. (F.R.I. records)
Pinus radiata D. Don (F.R.I. records)
Pinus patula Schl. & Cham. (F.R.I. records)
Pinus nigra Arnold (F.R.I. records)
**Pinus sylvestris* Linn. (F.R.I. records)
**Pinus ponderosa* Laws. (F.R.I. records)
**Pinus contorta* Dougl. (F.R.I. records)

[1] Authorities for indigenous species as in Cheeseman (1925).
[2] Authorities for exotic species as in Weston (1957).

Pinus muricata D. Don (F.R.I. records)
**Pinus pinaster* Aiton (F.R.I. records)
**Pinus banksiana* Lamb (F.R.I. records)
Pinus strobus Linn. (F.R.I. records)
Larix decidua Miller (F.R.I. records)
Larix leptolepis (Sieb. & Zucc.) (F.R.I. records)
Pseudotsuga taxifolia Britt. (*menziesii* (Mirb.) Franco) (F.R.I. records)
**Sequoiadendron giganteum*[3]. (Lindl.) Buchholz (F.R.I. records)
**Sequoia sempervirens* (D. Don) Endl. (F.R.I. records)
Chamaecyparis lawsoniana (A. Murr.) Parl. (F.R.I. records)
Cupressus macrocarpa Hartw. (F.R.I. records & Hudson, 1928)
Tsuga heterophylla (Raf.) Sarg. (F.R.I. records)
Eucalyptus spp. (F.R.I. records)
**Alnus spp.* (F.R.I. records)
Ulex europaeus Linn. (F.R.I. records)
**Quercus spp.* (F.R.I. records)

Acknowledgments

The writer wishes to thank all those who, in offering advice and material, helped him draft this paper.

References

Brues, C. T., Melander, A. L., Carpenter, F. M., 1954. Classification of insects. Bull. Mus. Comp. Zool. Harvard, Vol. 108.

Chappell, A. V., 1929. Biological Notes on N.Z. Lepidoptera. Trans. Proc. N.Z. Inst., 60: pp. 259–264.

Cheeseman, T. F., 1925. Handbook of the New Zealand Flora. 2nd Edition, Govt. Printer, Wellington.

Clark, A. F., 1936. The needle-tying moth (*Tortrix excessana* Walk.) N.Z.J. Sci. Tech., 17: 5, pp. 679–685.

Dumbleton, L. J., 1932. The apple leaf roller (*Austrotortrix postvittana* (Walk.)) N.Z. J. Sci. Tech. 14: pp. 83-92.

Hinton, H. E., 1946. On the homology and nomenclature of the setae of lepidopterous larvae and some notes on the phylogeny of the Lepidoptera. Trans. R. ent. Soc. Lond., 97: pp. 1–37.

Hudson, G. V., 1928. The Butterflies and Moths of New Zealand. Ferguson & Osborn, Wellington.

——— 1939. Supplement to the Butterflies and Moths of N.Z. Ferguson & Osborn, Wellington.

——— 1950. Fragments of Entomology. Ferguson & Osborn, Wellington.

Jeffreys, F. J., 1939. *Carposina adreptella.* Trans. Proc. Roy. Soc. N.Z., 69: pp. 341–346.

Peterson, A. H., 1948. Larvae of insects. (An introduction to Nearctic Species.) Part 1, Columbus, Ohio.

* Recorded from, but not reared through on these host species.

[3] Authority for this name as in St. John, H. and Krauss, R. W., 1954.

St. John, H. and Krauss, R. W., 1954. The taxonomic position and scientific name of the big tree known as *Sequoia gigantea*. Pac. Sci., 8: 341–358.

Watt. M. N., 1920. The leaf-mining insects of N.Z. I. The genus *Parectopa*. Trans. Proc. N.Z. Inst., 52: 439–466.

—— 1921. The leaf-mining insects of N.Z. II—The genus *Nepticula*. Trans. Proc. N.Z. Inst., 52: 197–219.

Weston, G. C., 1957. Exotic Forest Trees in New Zealand. (Statement prepared for 7th British Commonwealth Forestry Conference) N.Z. Forest Service.

Resistance of Insects to Insecticides

D. Spiller,

Plant Diseases Division, Department of Scientific and Industrial Research, Auckland, New Zealand.

[*Presidential Address delivered to the Ent. Soc. of N.Z. Annual Conference, May 13, 1958, Nelson.*]

1. Introduction

There are a number of recent publications reviewing our knowledge of the resistance of insects to insecticides; early instances are fully covered by Prof. A. W. A. Brown in his book "Insect Control by Chemicals" (1951). The information was brought up to date by the full reviews of Metcalf (1955b) and Weissmann (1955). Since these reviews, no full review has appeared. There is an excellent short chapter on resistance in "Organic Insecticides" by Metcalf (1955a) and several authors have discussed special aspects; quantitative changes (Hoskin and Gordon, 1956); genetics (Milani, 1956 and 1957; Crow, 1957); physiological mechanisms (Chadwick, 1955); enzymatic detoxification of DDT (Kearns, 1955 and 1956); public health insects (Busvine, 1957; Quarterman and Schoof, 1958; Brown, 1958). There are also a number of others, the multiplicity of reviews reflecting the importance of the problem and the concern it is causing those responsible for protecting the health and food of the people.

Perusal of these reviews might give the impression that resistance to chemicals had developed mainly in insects of public health importance and that largely the agricultural entomologist had escaped this infliction. Unfortunately this is not true, for although there is vastly more information about the nature and inheritance of resistance of public health insects than of agricultural insects, this partly reflects the fact that many public health insects, as for example houseflies, have relatively short life cycles and are rather easily maintained in laboratory culture the year round. By comparison, many agricultural pests must be maintained on living plants (the rearing of which is a tedious diversion) and often have few generations a season, those with short life cycles such as aphids and mites often being considered too small for convenience.

Often it is said that such and such an insect is resistant to a particular insecticide, for example DDT. Although this is never true, for no species has yet become insecticide resistant, it remains a convenient way of avoiding an overlong statement "that the population of a (given) species occupying a particular (named)

area has developed resistance to DDT". Just as the Mendelian population and not the species is recognized today as the basic taxonomic unit, so undoubtedly the Mendelian population is the unit in which resistance evolves. As no two populations are identical, it is not surprising when the use of insecticides leads to early emergence of resistance in one population while another remains susceptible. However, because insecticides have catastrophic effects on susceptible populations, these are readily displaced by resistant genotypes if the areas of distribution are contiguous.

2. Incidence of Resistance

Symphyla. The garden centipede *Scutigerella immaculata* has possibly developed DDT_r in Indiana, where it has been necessary to increase the rate of application of DDT from 4·5 to 25lb. per acre (Babers, 1953).

Insecta. There do not appear to be any cases of insecticide resistance recorded for Thysanura, Collembola, Orthoptera, or Dermaptera.

Among Blattaria, the American cockroach *Periplaneta americana* has a natural resistance to chlorthion (Laake, 1955) but no resistance to insecticides has developed in the field. The German cockroach *Blattella germanica* has developed resistance in the field to chlordane and pyrethrins (Brown, 1958). The $chlordane_r$ strain is markedly cross resistant to dieldrin (Fisk and Isert, 1953) and somewhat cross resistant to lindane (Grayson, 1954). In the laboratory, resistance has been developed to DDT (Grayson, 1953) but DDT_r does not appear to occur in the field.

In some areas termites may have become resistant to pentachlorphenol (Babers, 1953).

No instance of insecticide resistance has been reported in the Corrodentia (psocids) or the Mallophaga. Of Anoplura, only the body louse (*Pediculus humanus coporis*) is known to be resistant. DDT_r strains were first found in Korea and are now known to be widespread. More recently BHC_r has appeared in Iran, and is known to be present elsewhere (Brown, 1958).

Several thrips are known to be resistant. The citrus thrips, *Scirothrips citri*, and the gladioli thrips, *Taeniothrips simplex*, have both developed field resistance to tartar emetic (Brown, 1951). The onion thrips, *Thrips tabaci*, has developed DDT_r in Texas and in these areas either is, or is becoming, resistant to dieldrin, heptachlor and toxaphene (Richardson and Wene, 1956).

Several Heteropterous Hemiptera have become insecticide resistant. The bed bug, *Cimex lecticularis*, has developed DDT_r and BHC_r; the tropical, *C. hemipterus*, DDT_r and $dieldrin_r$ (Brown, 1958) and there is some evidence for DDT_r in the Lygaeid bugs,

Lygus elisus, L. hesperus and *L. desertus,* in both Arizona and Washington (Menke, 1954; Hills *et al,* 1956).

Many Homoptera are insecticide resistant. Classical cases are the resistance of San Jose scale, *Aspidiotus perniciosus,* to lime sulphur (Melander, 1914) and the marked HCN_r of citrus red scale, *Aonidiella aurantii,* the black scale, *Saissetia olea,* and the citricola scale, *Coccus pseudomagnoliarum* in California (Brown, 1951). Curiously, none of these insects is known to have developed resistance to more modern insecticides. The walnut aphid, *Chromaphis juglandicola,* is sevenfold $parathion_r$ in California (Michelbacher, *et al,* 1954). There is evidence that the green peach aphid, *Myzus persicae,* has become difficult to control with parathion and malathion in Washington peach orchards, but parathion still gave excellent control when the orchard strain was reared in the laboratory. The differences in susceptibility between field and laboratory reared populations are not understood (Anthon, 1955), and there is now evidence that alfalfa aphid, *Therioaphis maculata,* is fourfold resistant to parathion in California (Stern and Reynolds, 1957). The leaf hopper, *Erythroneura lawsoniana,* on apples in Kentucky (Hamilton and Fahey, 1954) and the grape leaf-hopper, *E. variabilis,* on grapes in Arizona and California (Barnes *et al,* 1954) are DDT_r. In California the southern garden leaf hopper, *Empoasca solani,* was effectively controlled by DDT in 1952, but failures were reported in subsequent years and DDT_r is suspected (Reynolds and Deal, 1956).

Two Lepidoptera are known to have become somewhat resistant to arsenicals. A strain of peach twig borer, *Anarsia lineatella,* resistant to basic lead arsenate has been reported from California. Lead $arsenate_r$ codling moth occur in America and Australia. In America this resistance is due to an enhanced ability to reject treated stings and still find an entry into the apple, not to a greater resistance to arsenic which is still as toxic when ingested or injected. Hence cryolite, barium fluorosilicate and rotenone are also less effective (Brown, 1951). Codling moth exhibits mild DDT_r in several parts of the United States (Glass and Fiori, 1955; Hamilton, 1956) and spectacular DDT_r in Australia (Smith, 1955). The cabbage white butterfly, *Pieris rapae,* is DDT_r in Wisconsin (McEwen and Chapman, 1952) and Japan (Kojima *et al,* 1958), the cabbage loper, *Trichoplusia ni,* is DDT_r in New York (McEwen and Hervey, 1956) and the diamond-backed moth, *Plutella maculipennis,* DDT_r in Java (Ankersmit, 1953). The salt marsh caterpillar, *Estigmone acrea,* a late season cotton defoliator, is $toxaphene_r$ or toxaphene-DDT_r in Arizona (Stevenson *et al,* 1957) and another cotton defoliator, the cotton leaf worm, *Alabama argillacea,* is tenfold $toxaphene_r$ in Texas (Ivy and Scales, 1954). This last instance is of particular interest for the pest does not overwinter in the United States; resistance must therefore have arisen in

Central or South America from whence the American infestation originates annually. A third cotton pest, the spiny boll worm, *Earias insulana*, is endrin$_r$ in Israel (Ascher and Tahori, 1957). The latest and perhaps most interesting case of insecticide resistance amongst Lepidoptera is the development of DDD$_r$ in the red-banded leaf roller, *Argyrotaenia velutinana*, (Glass, 1957) which (like our apple leaf roller, *Austrotortrix postvittana*) is naturally resistant to DDT, but was adequately controlled by the very similar DDD from 1949 until 1954. The recent development of DDD$_r$ indicates the possibility that two very similar materials may be detoxified by different routes in the same insect.

The southern wire worm, *Conoderus falli*, has developed rather marked chlordane$_r$ in California and is probably also moderately resistant to aldrin, dieldrin and heptachlor even though these materials have not been used as soil insecticides in the area where chlordane$_r$ is present. As a possible instance of the predominant genic as opposed to environmental contribution to the emergence of resistant strains, it may be worth mentioning that the sympatric species, *Conoderus amplicollis*, has not developed resistance, although it has been equally exposed to insecticide (Reid and Cuthbert, 1956).

The Mexican bean beetle, *Epilachna varivestis*, is about four-fold resistant to rotenone in Connecticut and Carolina (Brett and Brubaker, 1955).

Colorado beetle, *Leptinotarsa decimlineata*, is said to be DDT$_r$ in Spain (Kuhn and Low, 1955).

In Connecticut the potato flea beetle, *Epitrix cucumeris*, became DDT$_r$ after only five or six generations had been exposed to insecticide (Kring, 1956); DDT$_r$ possibly also occurs in Virginia (Hofmaster, 1956). With these four beetles all stages of development probably contact insecticide, leading to the rapid establishment of resistance through multiple selection in each generation. The same effect occurs when insecticide is incorporated in the breeding medium of houseflies.

In Carolina and Louisiana the boll weevil, *Anthonomus grandis*, has become about 150-fold endrin$_r$ with some cross resistance to other chlorinated hydrocarbon insecticides (Roussel and Clower, 1957).

No pest Hymenoptera are known to be insecticide resistant. The parasite, *Macrocentrus ancylivorus*, has developed DDT$_r$ in the laboratory (Pielou and Glasser, 1951), and there is some circumstantial evidence which suggests that the apple woolly aphid parasite, *Aphelinus mali*, has developed field resistance to DDT and lindane in New Zealand. It would be of the greatest interest if this observation were substantiated by laboratory tests for generally it has been considered that the upsets in natural control brought about by the use of insecticides are a necessary and permanent affliction, and it

appears to have been seldom stressed, if not actually forgotten, that an effective biological balance may re-establish if parasites develop resistance to insecticides.

There are many cases of insecticide resistance amongst Diptera.

Houseflies, *Musca domestica*, resistant to DDT are now everywhere. As other insecticides were used for fly control, so has resistance developed, so that today, BHC_r, $dieldrin_r$, $chlordane_r$, $parathion_r$, $diazinon_r$, $restitox_r$, and $malathion_r$ strains occur in the field. Selection in the laboratory has produced strains resistant to almost every insecticide or combination, although resistance is not always marked.

In addition to inducing resistance, the use of dieldrin is often followed by exceptionally large numbers of houseflies; this "dieldrin phenomenon", first reported from Georgia, has now occurred in East Africa, Liberia, Saudi Arabia, India and Japan (Brown, 1958). The causes are little understood, but it is probably not due to a reduction of predators and parasites.

The stable fly, *Stomoxys calcitrans*, has developed DDT_r in Sweden (Sjellander, 1949).

The sheep blowfly, *Lucilia cuprina*, has recently developed $dieldrin_r$ in Australia (Shanahan, 1958a, b); the blowfly, *Chrysomia putoria*, is both BHC_r and highly resistant to diazinon. Use of malathion against the $diazinon_r$ strain led to some $malathion_r$ and decreased $diazinon_r$ (Quarterman and Schoof, 1958).

The mosquito*, *Culex pipiens*, is both DDT_r and $chlordane_r$; *C. fatigans*, DDT_r, BHC_r, dieldrin and $chlordane_r$; *C. tarsalis*, DDT_r, $dieldrin_r$ and $malathion_r$.

The yellow fever mosquito, *Aedes aegypti*, is DDT_r. The salt marsh mosquitoes, *Aedes taeniorhynchus* and *A. sollicitans*, are DDT_r and appear to be developing BHC_r and $dieldrin_r$. The floodwater mosquitoes, *A. nigromaculatus* and *A. dorsalis*, are DDT_r and $toxaphene_r$, the rice field mosquito, *Psoraphora confinis*, is DDT_r.

Amongst Anophelenes, *Anopheles sundiacus* is DDT_r, DDD_r, $methoxychlor_r$ and $perthane_r$; *A. stephensi* and possibly *A. maculipennis* are DDT_r; *A. gambiae* and *A. quadrimaculatus* are $dieldrin_r$; *A. subpictus* is DDT_r and $dieldrin_r$; and *A. sacharovi* is DDT_r, $dieldrin_r$ and $chlordane_r$.

The filter fly, *Psycoda alternata*, is DDT_r (Bruce and Decker, 1950) and the lake-breeding midge, *Glyptotendipes paripes*, developed BHC_r within several months and EPN_r within a year (Lieux and Mulrennan, 1956).

DDT_r has been repeatedly produced in laboratory strains of the genetics fly, *Drosophila melanogaster*, usually with the intent of

* For relevant references to insecticide resistance in mosquitoes refer to Busvine, 1957; Quarterman and Schoof, 1958, or Brown, 1958.

studying the inheritance of resistance. In appropriate circumstances (which may be rare) resistance also develops in the field. At least, flies collected at Hikone City, Japan, where intensive DDT spraying for malaria control had occurred (Tsukamoto and Ogaki, 1957), proved to be resistant in the laboratory (Ogaki and Tsukamoto, 1953). Interestingly, the inheritance of laboratory-induced DDT_r is polygenic with contributions from every chromosome (Crow, 1954; King, 1955), that of the field-collected Hikone strain, monofactorial on the second chromosome (Ogaki and Tsukamoto, 1953), a warning that different mechanisms of resistance may evolve in different populations of the same insect.

The human flea, *Pulex irritans,* is DDT_r in several parts of the world. The dog flea, *Ctenocephalides canis,* and the cat flea, *C. felis,* are markedly DDT_r, and more recently $chlordane_r$ and $dieldrin_r$ have appeared in the United States (Brown, 1958).

Acarina. The brown dog tick, *Rhipicephalus sanguineus,* is $chlordane_r$ in New Jersey and elsewhere in the United States (Hansens, 1956). Two cattle ticks, the blue tick, *Boophilus decoloratus,* in South Africa and the southern cattle tick, *B. microplus,* in Australia are both sodium $arsenite_r$, BHC_r, DDT_r and $dieldrin_r$, the South African species is resistant and the Australian species known to be cross resistant to toxaphene and dieldrin (Brown, 1958).

The Tetranychid mites have many examples of resistance to chemicals. Generally the reports are based on persistent failure to obtain control in the field, and laboratory investigations are often too meagre to be convincing. Further, the identification of Tetranychid mites is often difficult and there have been many new species and synonymies in recent years which now raise doubts about the specific validity of many identifications. Therefore, rather than catalogue the various alleged species which have developed resistance, the information may be summarised by saying that Tetranychid mites have developed resistance to parathion with strong cross resistance to other organophosphorous insecticides and DMC, to malathion, azobenzene, aramite, chlorobenzilate, chlorobenzide, tedion and ovex (March, 1958). That is, to approximately the full spectrum of modern organic acaricides.

In summary, field resistance to insecticides has been recorded for 57 insects, 3 ticks, a number of Tetranychid mites and possibly one symphylan. But these are only the recorded cases and, particularly amongst agricultural pests, many other cases are known or suspected but have yet to be investigated or recorded.

3. Nature of Resistance

Certain terms require definition. The word tolerance is a suitable neutral term to describe the reaction of the whole insect to

insecticide. Although the tolerance of individual insects cannot be measured, it is not too difficult to visualize that at any instant each insect has a definite tolerance, although this may not be the same as it had before or will have later. Quantitatively the tolerance is expressed as the amount of insecticide which, if applied in a standard manner at a particular time to a particular insect, just kills or, if preferred, just fails to kill the animal.

Susceptible insects are those with a "normal" range of tolerances. To the extent that it is difficult to define what is meant by "normal", the term is unsatisfactory, but presumably a "normal" range of tolerances means a unimodal, homogenous assemblage of values such as might be built up from a series of populations which have been reared in the usual manner or collected in the usual habitat and are known not to have been selected with insecticide in previous generations. (The intrusion of unimodal and homogenous into this description is necessitated by the fact that some natural populations already contain a proportion of individuals which have abnormally high tolerances and are obviously distinct outliers in an otherwise relatively uniform assemblage.)

As obvious extensions of the term susceptible, more susceptible and less susceptible describe either individuals or populations with lower or higher tolerances. But resistant insects also have higher tolerances and the terms "less susceptible" and "resistant" could, and sometimes are used to describe the same thing. However, it is convenient to use the terms "more susceptible" and "less susceptible" to distinguish changes in insecticide tolerance arising from differences in environmental conditions of rearing or testing, or nutrition, or size, stage and age, that is, phenotypical variation, and to reserve the terms "resistant" and "resistance" for increased tolerance that is known or thought to be inherited or genotypic. This convention of usage, useful as it is, accentuates the essentially unsatisfactory nature of the term "susceptible" and variants to describe the phenomenon encountered, for the range of phenotypic plasticity is genetically determined also and what might be a decreased susceptibility in one generation might be resistance in the next. Size is an important character which can be greatly influenced by nutrition and rearing conditions. It also greatly affects the insecticide tolerance of individuals, so that small specimens are more susceptible, large specimens less susceptible. But the size attained in any environment is under genetic control and hence selection for large size would increase insecticide tolerance while the main effect of selection with insecticide might well be to eliminate the smaller genotypes, resulting in greater average size and hence increased insecticide tolerance in the next generation. Are these larger and more tolerant strains to be termed less susceptible, or are they more resistant? What becomes apparent is that increases and decreases in susceptibility can occur without

selection, whereas development of resistance requires selection—that is, that only a selected portion of the population is bred from in each generation. Although only insects are considered here, it might be well to mention that some workers reject the role of selection in the development of drug resistance in microbial populations (Schnitzer and Grunberg, 1957) and that selection is therefore not a necessary or universal mechanism. With insects, cases may yet occur where resistance emerges without selection, but such instances have not yet been described.

The tolerance of individual insects cannot be measured. This inability to measure the individual tolerance constitutes the major difficulty in the investigation of susceptibility and resistance. However, by applying a known dose to an individual it is possible to find out whether the tolerance of that insect is above or below the applied dose. Pooling a large number of such observations on insects from the same population gives the proportion of individuals with greater or less tolerance than the applied dose. Using a different dose gives a different proportion, and by pooling results from a series of doses a frequency distribution of the magnitudes of the tolerances of the individuals in the various samples can be arrived at and from this the probable distribution of tolerances in the population can be estimated. This in turn permits calculation of the mean or average tolerance (LD_{50}) or, if preferred, the modal or most frequent value. Except that an individual tolerance probably lies between the dose applied and extreme upper or lower range of the distribution, the method tells us nothing about the tolerance of any individual in the population. The method is the method of quantal responses, often but erroneously referred to as the log-probit method because of an almost universal acceptance and popularity of a particular computational method used in the analysis of quantal data. Indeed, to some insect toxicologists the log-probit method has become a belief, suggestions of shortcomings a heresy. Therefore it cannot be too strongly stressed that the method of quantal responses makes no assumptions regarding the form of the distribution curve of individual tolerances. These assumptions are made only when the investigator chooses a particular method of analysing and interpreting the data. Therefore, if the data is not adequately described by the model chosen, be this log-probit or any other, the fault lies in the inadequacy of the model, not in the distribution itself.

Because a resistant insect is one which shows an abnormally high insecticide tolerance, it is only reasonable to inquire how this abnormally high tolerance is achieved. My interpretation of the available evidence is that there are two distinct ways in which insects can become resistant to insecticides and that hence there are, primarily, two types of resistance. For the first I use the term "multicomponent resistance", but, if preferred, it could equally

well be called "hypertolerance" or "generalised resistance". The second can be called "specialised resistance" or "specific resistance". The terminology is not important, provided the differences between the two types are clearly understood.

Multicomponent, or generalised resistance, is akin to the fine tuning of a racing car. It requires a large number of fine adjustments. None of the adjustments are particularly important in themselves, but in the aggregate a spectacular result can be achieved because all adjustments are directed toward the same goal. In biological terms, there are many, probably unrelated, factors or components which affect the tolerance of an insect to insecticide. Possible examples are size, thickness and structure of the cuticle, amount and composition of lipoid, ionic balance of the blood, structure of the perineurium, molecular spacings of the nerve membrane, and, of course, behaviour. From specimen to specimen each component must vary in magnitude: at one end of its range tending to maximise its contribution to the tolerance, at the other end of the range making a smaller contribution. In some specimens, merely by chance alone, each component may make the maximum possible contribution, or contrariwise, in a few individuals each component may make a minimum contribution, but for most individuals the contribution of each component will not reach these extreme values and some of the contributions will increase, some will decrease the tolerance. It is suggested that it is this summation of a number of independently variable components which leads to the unimodal distribution* of tolerances in a "normal" population of insects.

Even though we do not know what the components of tolerance are, we do know that they must be susceptible to selection, for, in the last analysis, all variation is under genic control. Selection with insecticide progressively sorts out the genic combinations which increasingly restrain most of the components of tolerance from entering the lower part of their range and thus tolerance is increased. Some components presumably remain unselected or take the lower values because their high values require genic constitutions incompatible with the genic constitutions required in the solution of other and perhaps more important components. As the number of components of tolerance is probably large, implying many genes distributed on every chromosome, it is to be expected that selection for this type of resistance will take a number of generations and that a plateau of resistance will eventually be reached, beyond which there are but small and erratic gains and losses in resistance even under a harsh selection programme. Further, it is obvious that the particular balance of components

* The tolerances will be normally distributed if the effects of the contributions of each component are additive, lognormal if the contributions are multiplicative.

that is achieved will depend on many factors. One is the presence or absence of particular genes and their frequency in the gene pool of the first selected population. Another might be selection pressure, for under too harsh a selection programme some genes perhaps involved in maximising a major component of tolerance, may not have time to be distributed throughout the population before the specimens which carry them are eliminated. Likewise, some genes may be lost if the manifold effects of selection produce gene combinations independent of resistance but deleterious to the vigour or breeding of the population. What is to be expected is that, depending upon the ebb and flow of these various effects, the selected population will eventually achieve a genic balance which maximises the tolerance. But it is not to be expected that the same route will always be traversed, nor that the final gene pool of independently selected populations will be identical, nor that the genes present will be integrated in an identical manner (King, 1955). Thus some degree of resistance will be achieved under every selection programme, but each selected population may achieve resistance in a different manner. It is hardly likely that resistance of this type will approach a virtual immunity. The multiple adjustment of many factors can hardly do more than achieve a several-fold increase in the tolerance.

Virtual immunity to insecticide demands some specific mechanism, the most obvious and established of which is detoxification of the insecticide. Other mechanisms are either known or have been suggested. It is possession of a specific mechanism of resistance which characterises the second type of resistance, not the virtual immunity which the mechanism sometimes confers on the insect.

DDT_r houseflies possess a specific mechanism of resistance in the enzyme DDT dehydrochlorinase (DDT'ase) which both *in vivo* and *in vitro* breaks down DDT to the insecticidally inert material DDE (Kearns, 1955). Much has been made of the fact that DDT_r houseflies have within their bodies amounts of DDT that would be rapidly fatal to susceptible houseflies. This fact, which may be referred to as Winteringham's paradox, has seemed to many an insuperable hurdle to the understanding of resistance and has led some to doubt or reject the importance of dehydrochlorination as the mechanism of resistance. The question has even been posed, whether increased detoxification occurs because the insect is resistant rather than that resistance is conferred by dehydrochlorination (Chadwick, 1952). Various arguments can be used to counter this suggestion, and the most convincing have recently been put by Miyake, Kearns and Lipke (1957). But whether these arguments are convincing or not, Winteringham's paradox is no paradox! That it occurs is but evidence (and there is other evidence) that the two types of resistance discussed above coexist in

houseflies. Indeed it could not be otherwise. If the genic components for DDT dehydrochlorination occur within the original population, selection with DDT will be required to increase the gene frequency within the population. While this selection is going on there will also be selection for multicomponent resistance. This is the solution of Winteringham's paradox. The DDT_r flies can tolerate within their bodies amounts of DDT which would be rapidly fatal to susceptible houseflies because they have two mechanisms of resistance. The one, a specific mechanism of detoxification greatly reducing the amount of DDT, the other a multicomponent resistance enabling them to tolerate increased amounts of unchanged DDT. As with most other paradoxes, the solution lies within the paradox itself rather than in any conflict of facts; the comparison should be not with susceptible flies but with flies selected for multicomponent resistance but lacking a detoxification mechanism. There is some further evidence that this is the correct explanation.

Many of the materials commonly termed synergists increase the toxicity of DDT to DDT_r houseflies by inhibiting DDT'ase and so preventing detoxification. Some of these materials are very effective, but it has been noted that however much synergist is applied, the DDT tolerance of synergist-treated flies is always somewhat more than that of comparable unselected or non-resistant flies (Perry *et al,* 1953). Perhaps this is because the synergist does not completely block the detoxifying mechanism, but a more likely explanation is that selection for a specific mechanism (detoxification) has resulted in generalised resistance to DDT; when detoxification is prevented, the multicomponent resistance remains.

It is often found that insects resistant to one insecticide are also resistant to others with which previously they have never been in contact. This is the problem of cross resistance. Consider first insects which have specific mechanisms of resistance. Here cross resistance depends on the specificity of the resistance mechanism. If, for example, DDT'ase breaks down BrDDT as readily as DDT itself, then obviously DDT_r flies will also be resistant to BrDDT. If another material, lindane for example, is not affected by DDT'ase, this explains the susceptibility of DDT_r flies to lindane. If the enzyme does detoxify the insecticide, but less effectively than DDT is detoxified, then intermediate cross tolerance is to be expected as with DDD and methoxychlor. In general terms the problem does resolve itself in this way, but there are notable exceptions involving non-reciprocal cross tolerance. DDT_r flies are usually cross tolerant to methoxychlor, but houseflies are known resistant to methoxychlor but susceptible to DDT. DDT_r insects are usually cross resistant to DDD. However, the red-banded leaf roller is naturally resistant to DDT but susceptible to DDD. DDT_r flies are usually cross tolerant to dilan in Denmark, but are susceptible

in the United States (Keiding, 1955). DDT_r insects are usually not cross tolerant to organophosphorous compounds, but those resistant to organophosphorous compounds are often highly cross resistant to chlorinated hydrocarbon insecticides.

Cross resistance usually occurs between insecticides with similar modes of action. This appears to be an indirect correlation, the relationship being with the specificity of the resistance mechanism, not with the mode of action, for specific resistance seems always to arise by the intrusion of some process between the insecticide and the site of action, not by modifications at the site of action. Perhaps these are usually so specialized that the possibilities of change have become very restricted and this is why their function is so readily upset by insecticides and why the nervous system is the favoured target for insecticides. Hence a resistance mechanism ceases to be an effective mechanism if the amount of insecticide reaching the site of action becomes greater than the normal tolerance of the insect. Therefore, when a specific mechanism confers resistance against one insecticide but does not confer resistance to the second, it is not valid to conclude that the two insecticides have different modes of action. The only valid conclusion is that the mechanism which renders the first insecticide ineffective does not have the same effect upon the second insecticide. What this really amounts to is that the mode of action of insecticides is less specific than the mechanisms which confer resistance. DDT and dianysylneopentane almost certainly have a common mode of action, but because the enzyme which detoxifies DDT to DDE does not detoxify dianysylneopentane, this material is still effective against (some) DDT_r houseflies. Hence mode of action is not involved in cross resistance, and it is possible to have negligible cross resistance between insecticides even though they have the same mode of action.

Cross tolerance also occurs in insects which have multicomponent resistance, which, as we have seen, is brought about by adjustment of a large number of components. There is, however, no reason to believe that the components which confer generalized resistance to one insecticide confer resistance to other insecticides. Generalized resistance to, say, pyrethrum, may be built up from a quite different set of components to resistance to DDT and, indeed, if any components are common it is conceivable that the adjustments which increase tolerance towards one insecticide may decrease tolerance towards another. But obviously there will be cases where the adjustments which maximise the contributions of a number of components to DDT resistance will also confer resistance to another insecticide. When this occurs cross tolerance will appear. In multicomponent resistance, therefore, the degree of cross tolerance is the summation of the contributions of the shared components of resistance. If the summation of these contributions is

positive the toxicity of the two insecticides will be positively correlated. If the summation of the contributions is negative the toxicity of the two insecticides will be negatively correlated. And if the summation were zero, there would be no correlation, or no cross tolerance, but this case can hardly be distinguished from the situation where there are no common components in the make-up of the tolerances to the two insecticides.

Thus cross tolerance to insects with specific mechanisms of resistance has an entirely different basis from cross tolerance in insects with multicomponent resistance. Therefore it is not to be expected that either the occurrence or the degree of cross tolerance will be identical when the two types of resistance are compared: DDT_r *Drosophila* are about 50 to 70 per cent. cross tolerant to lindane (Weiner and Crow, 1951) but DDT_r houseflies (a specific mechanism) are so little cross tolerant to lindane that this might reasonably be attributed to the generalized resistance they also possess.

I have already said that in insects there is no known case where resistance has developed without selection. This implies that resistance does not develop in direct response to the particular insecticide—that is, that resistance is not induced as an adaptation to insecticide. All the available evidence suggests that the genes for resistance pre-exist in the unselected population, and that the role of the insecticide is to sort out and increase the frequency of these genes. Sometimes, as in generalised resistance, particular gene combinations are required, but here again the role of the insecticide is to eliminate the gene combinations which make the insects susceptible and thus increase the frequency of the gene or gene combinations which confer resistance until, eventually, a resistant race emerges.

There is no difficulty in understanding how every population, if not restricted by complete homozygosity, can work out some particular gene combination which tends to increase the tolerance of the insecticide with which it is selected. This is the basis of my multicomponent resistance discussed earlier, and I believe that such potentialities for development of resistance are inherent in every Mendelian population. Some of these populations will have initial gene pools which, however selected or integrated, are incapable of achieving more than fractional increases in their tolerance. Other populations with differing gene pools may have the potentiality of increasing their resistance many times. Hence I hold out no hope whatsoever that some insects will always remain as susceptible to an insecticide as they are now. The increase in resistance may be small, but with some insects even a twofold increase in tolerance might result in a treatment becoming uneconomic.

More difficult to comprehend is the seemingly limitless potentialities of some species to develop specific mechanisms of resistance to a wide range of unrelated insecticides.

Small laboratory populations of houseflies have often been successfully selected for DDT resistance. In one laboratory, when DDT_r emerged it was found that selection with lindane quickly produced a DDT-$lindane_r$ strain and that selection of the DDT-$lindane_r$ population with Prolan soon produced a DDT-lindane-$Prolan_r$ strain. Are we now to believe that these small laboratory populations happened to contain the genes for DDT_r, for $lindane_r$, and for $Prolan_r$, or are we to believe that there is some co-relationship and that they are to be considered additional changes in the same basic resistance mechanism (March, 1952) in spite of the fact that often resistance to one can be developed without cross resistance to the other?

To my mind there is not yet enough evidence to say with certainty how resistance develops. Undoubtedly it is true that the genes conferring resistance exist in the population prior to the application of insecticide, but whether it is always true in the simple way at present visualised is an open question. The fact that the level of DDTase in DDT_r flies can be considerably increased by further selection with DDT plus synergist may constitute evidence that the amount of enzyme is under genetic control. If true, it would appear that selection operates on two components of resistance, the first the presence or absence of a (recessive) gene for DDTase, and the second a set of genes which control the amount of enzyme produced. This would explain the rather slow emergence of resistance even under harsh continuous selection, for when adult houseflies are selected with DDT, there is typically an initial period of twenty to thirty generations during which a five or tenfold increase in resistance occurs, followed by a phase in which resistance may increase severalfold in each generation and within six to twenty generations achieve a virtual immunity (Metcalf, 1955a). This picture is hardly compatible with the general concept that the genes for resistance pre-exist in the population, that is in the sense that homozygosity for the gene confers full resistance. The usual explanation is that the gene frequency is low and sometimes it is said to be very low. This cannot be true. In a laboratory population at least one individual must carry the gene, or a resistant population cannot arise, and most but not all laboratory attempts to induce resistance are successful. If the gene is carried by only one fly in an initial population of 100 flies and selection is at 90%, one-tenth of the F_1 will carry the gene in heterozygous condition. After selection the population would be pure heterozygous and the F_2 would contain three genotypes, a quarter susceptible, a half heterozygous resistant and a quarter homozygous resistant. With further selection the F_3 would be

homozygous resistant—that is, full resistance after three selections. Obviously these calculations are an oversimplification in that selection is of resistant phenotypes not genotypes, but even allowing for this, given the minimum gene frequency (that is one individual in the initial population) and a harsh selection programme, resistance should emerge in a few generations, which obviously bears no resemblance to what happens either in the field or in the laboratory when, say, adult houseflies are selected with insecticide.

Perhaps what actually occurs is that initially the flies carrying the resistant gene make rather small amounts of DDT'ase, conferring upon these individuals a slightly increased tolerance to DDT. But tolerance of an insect to any insecticide is the summation of many probably unrelated factors or components, the intensity of some being under genic control, others being phenotypical. Selection gradually maximises the genic components of tolerance, but during the process the small contribution made by a relatively minute amount of DDT'ase is overwhelmed in the ebb and flow of the selection of other components. During this process the DDT'ase gene will behave as an almost neutral gene remaining at about the same frequency, any increase or decrease being at the dictates of chance alone. When the population has worked out the particular combination of components which maximises the tolerance, flies which possess DDT'ase will have an advantage under selection. Then the population will become relatively homozygous for the DDT'ase gene and selection will begin to operate on the genes which control the amount of enzyme synthesised. This selection will cease when selection with DDT alone can no longer kill enough of the population to exert a further selective effect, but as has already been mentioned, selection to a higher enzyme level can be accomplished by selecting with DDT plus synergist (Moorefield and Kearns, 1955).

The essential feature of this hypothesis is that the genes for specific resistance cannot express themselves in the normal or susceptible insect because the contribution they make to the overall tolerance is too small to afford a selective advantage. In the rigidly selected genic background of multicomponent resistance even this small contribution has survival value and specific resistance can emerge. In general terms, the effect of the gene for specific resistance is masked by wide changes in tolerance, and in genetical terms, the gene has negligible penetrance in the susceptible phenotype but full penetrance in the phenotype of multicomponent resistance.

The hypothesis is not necessarily correct and obviously it does not apply to all cases of specific resistance. Dieldrin resistance in *Anopheles gambiae* is an obvious exception. There the genes for resistance pre-exist in unsprayed populations and express themselves fully, leading to the rapid development of resistance as soon as

dieldrin is used (Brown, 1958). But the hypothesis does fit most of the facts known about the evolution of resistance in many species, particularly houseflies. It explains the slow emergence of resistance, followed by rapid build-up; the increase in resistance following selection with DDT plus synergist; the rapid emergence of resistance to a second insecticide;† and, in houseflies, the virtual absence of DDT'ase in susceptible populations even though these are capable of developing DDT_r (Kerr *et al*, 1957). As such it may prove a refreshing basis for further experiment.

† When there is cross resistance, the common components have already been selected. The second multicomponent resistance is built on a foundation of shared components, not *de novo*. In every case there is a smaller gene pool for selection.

References

Ankersmit, G. W., 1953. Bull. ent. Res., *44*, 421–5.

Anthon, E. W., 1955. J. econ. Ent., *48*, 56–7.

Ascher, K. R. S., and Tahori, A. S., 1957. Nature, *179*, 324.

Babers, F. H., 1953. J. econ. Ent., *46*, 869–73.

Barnes, M. M., Flock, R. A., and Gormus, R. D., 1954. J. econ. Ent., *47*, 238–42.

Brett, C. H., and Brubaker, R. W., 1955. J. econ. Ent., *48*, 343.

Brown, A. W. A., 1951. *Insect Control by Chemicals*. John Wiley and Son, Inc., New York.

——— 1958. Bull. Wld. Hlth. Org., *18*, 309–21.

Bruce, W. N. and Decker, G. C., 1950. Soap and San. Chem., *26*, (3), 122–3, 145–7.

Busvine, J. R. 1957. Trans. R. Soc. trop. Med. Hyg., *51*, 11–36.

Chadwick, L. E., 1952. Am. J. Trop. Med. Hyg., *1*, 404.

——— 1955. *Origins of Resistance to Toxic Agents*. Academic Press, New York, pp. 133–64.

Crow, J. F., 1954. J. econ. Ent., 47, 393–8.

——— 1957. Ann. rev. Ent., *2*, 227–245.

Fisk, F. W., and Isert, J. A., 1953. J. econ. Ent., *46*, 1059–62.

Glass, E. H., 1957. J. econ. Ent., *50*, 674–6.

——— and Fiori, B., 1955. J. econ. Ent., *48*, 598–9.

Grayson, J. McD., 1953. J. econ. Ent., *46*, 124–7.

——— 1954. J. econ. Ent., *47*, 253–6.

Hamilton, D. W., 1956. J. econ. Ent., *49*, 866–7.

——— and Fahey, J. E., 1954. J. econ. Ent., *47*, 361–2.

Hansens, E. J., 1956. E. econ. Ent., *49*, 281–3.

Hills, A. D., Taylor, E. A., and Valcarce, A. C., 1956. J. econ. Ent., *49*, 94–5.

Hofmaster, R. N., 1956. *J. econ. Ent.*, 49, 530–3.

Hoskin, W. M., and Gordon, H. T., 1956. Ann. rev. Ent., I, 89–122.

Ivy, E. E., and Scales, A. I., 1954. J. econ. Ent., *47*, 981–4.

Kearns, C. W., 1955. *Origins of Resistance to Toxic Agents*. Academic Press, New York. pp. 148–59.

——— 1956. Ann. Rev. Ent., *1*, 123–148.

Keiding, J., 19[illegible]est Infestation Lab., 1952–53. Springforbi, p. 20.

Kerr, R. W., Venables, D. G., Roulston, W. J., and Schnitzerling, H. J., 1957. Nature, *180,* 1132–3.

King, J. C., 1955. Cold Spring Harbour Symposia on Quantitative Biology. *20,* 311–7.

Kojima, K., Nagae, Y., Ishizuka, T., and Shino, A., 1958. Botyu-Kagaku, *23,* 12–22.

Kring, J. B., 1956. J. econ. Ent., *49,* 557–8.

Kuhn, R., and Low, I., 1955. *Origins of Resistance to Toxic Agents.* Academic Press, New York, pp. 122–32.

Laake, E. W., 1955. J. econ. Ent., *48,* 753.

Lieux, D. B., and Mulrennan, J. A., 1956. Mosq. News, *16,* 201–4.

March, R. B., 1952. *Conference on Insecticide Resistance and Insect Physiology.* National Research Council, Pub. 219, p. 45–55.

——— 1958. Ann. rev. Ent., *3,* 355–76.

McEwen, F. L. and Chapman, R. K., 1952. J. econ. Ent., *45,* 717–22.

——— and Hervey, G. E. R., 1956. J. econ. Ent., *49,* 385–7.

Melander, A. L., 1914. J. econ. Ent., *7,* 164–173.

Menke, H. F., 1954. J. econ. Ent., *47,* 704–5.

Metcalf, R. L., 1955a. *Organic Insecticides.* Interscience Publishers, New York.

——— 1955b. Physiol. Revs., *35,* 197–232.

Michelbacher, A. E., Fullmer, O. H., Cassil, C. C., and Davis, C. S., 1954. J. econ. Ent., *47,* 366–7.

Milani, R., 1956 and 1957. Riv. Parassit., *17,* 233–246 and *18,* 43–60.

Miyake, S. S., Kearns, C. W. and Lipke, H., 1957. J. econ. Ent., *50,* 359–60.

Moorefield, H. H., and Kearns, C .W., 1955. J. econ. Ent., *48,* 403–6.

Ogaki, M., and Tsukamoto, M., 1953. Botyu-Kagaku, *18,* 100–4. (English trans. in Japanese Contributions to Study of the Insecticide-resistance problem, WHO, p. 28.)

Perry, A. S., Mattson, A. M., and Buckner, A. J., 1953. Biol. Bull., *104,* 426–38.

Pielou, D. P., and Glasser, R. F., 1951. Can. J. Zool., *29,* 90–101.

Quarterman, K. D., and Schoof, H. F., 1958. Amer. J. trop. Med. Hyg., *7,* 74–83.

Reid, W. J., and Cuthbert, E. P., 1956. J. econ. Ent., 879–80.

Reynolds, H. T., and Deal, A. S., 1956. J. econ. Ent., *49,* 356–8.

Richardson, B. H., and Wene, G. P., 1956. J. econ. Ent., *49,* 333–5.

Roussel, J. S., and Clower, D. F., 1957. J. econ. Ent., *50,* 463–8.

Schnitzer, R. J., and Grunberg, E., 1957. *Drug resistance of micro-organisms.* Academic Press, New York.

Shanahan, G. J., 1958a. Nature, *181,* 860–1.

——— 1958b. J. Aust. Inst. Agric. Sci., *24,* 157–8.

Sjellander, E., 1949. Lantmannen, *31,* 575–7.

Smith, L. C., 1955. J. Dep. Agric. S. Aust., *59* (1), 12–5.

Stern, V. M. and Reynolds, H. T., 1957. California Agric., *11* (2), 4 and 14.

Stevenson, W. A., Kaufman, W., and Sheets, L. W., 1957. J. econ. Ent., *50,* 279–80.

Tsukamoto, M., and Ogaki, M., 1957. Japan. J. sanit. Zool., *8,* 118–22. (English trans. in Japanese Contributions to the Study of the Insecticide-resistance Problem, WHO, p. 66.)

Weiner, R., and Crow, J. F., 1951. Science, *113,* 403–4.

Weissmann, R., 1955. Mitt. biol. Bund. Land-und Forst., *83,* 18–37.

Note Added in Proof.—A very extensive and authoritative review of insecticide resistance in arthropods of public health importance has now appeared. In addition to published information, the review contains much new information sent to or collected by the World Health Organisation: Brown, A. W. A., 1958. *Insecticide Resistance in Arthropods,* World Health Organisation, Monograph No. 38, pp. 1–240.

News Item.

Danaus chrysippus petilia Stoll. Breeding in New Zealand

This butterfly, known in Australia as "the lesser wanderer" and previously recorded as an occasional visitor to New Zealand. has now been found breeding in Taranaki.

During April and May, 1958, a number of caterpillars collected by Master John Wilkins among monarch larvae on swan plants (*Asclepias fruticosa L.*) in New Plymouth were sent to the Plant Diseases Division, D.S.I.R., Auckland, where they were reared and identified by Mr. K. A. J. Wise as *Danaus chrysippus petilia.*

The adult butterfly is similar to the monarch (*D. plexippus* (L.)) except that the wing veins are not marked in black. The larva has three pairs of filaments compared with two on the monarch, and each segment from mesothorax to 8th abdominal has a broad black band containing a pair of large yellow dorsal spots. The pale green chrysalis has several gold spots and a transverse dorsal abdominal band composed of an anterior thin black line and posterior thicker gold line.

(Communicated by K. A. J. Wise, Plant Diseases Division, D.S.I.R., Auckland.)

LEITZ MICROSCOPES

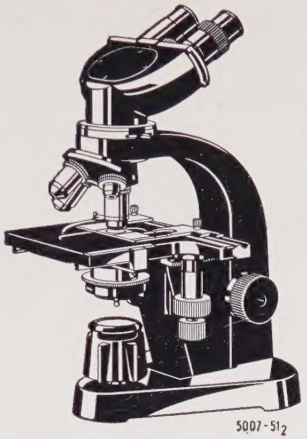
Ortholux

Dialux

Laborlux

S.M. small laboratory type

Phase Contrast
Flat Field objectives
Wide field eyepieces
Microtomes
Microphotographic apparatus
LEICA Cameras



5007-51/2

E. C. LACKLAND & Co. Ltd.

P.O. BOX 2812 AUCKLAND, C.1.

GEO. W. WILTON & CO. LTD.

Supplies for the Entomologist available from stock, including Microscopes, Dissecting Instruments, Pins, etc. Orders promptly supplied.

156 Willis Street, WELLINGTON.

63 Shortland Street, AUCKLAND.

THE NEW ZEALAND ENTOMOLOGIST

Vol. 2. No. 3. December, 1958.

CONTENTS

	Page
Dawson, E. W.: Exotic Millipedes (Diplopoda) in New Zealand	1
Lamb, K. P.: Aphid Sampling	6
Wise, K. A. J.: Notes on Insect Pests, 1957-58	12
May, Mrs. B. M.: An Aberration in *Baeocera scutellaris* (Redt.) (Coleoptera: Scaphidiidae)	15
Taylor, R. W.: Original Material of the Ant *Discothyrea antarctica* Emery, 1894, in New Zealand	17
Given, B. B.: A Container for Rearing Insects on Potted Plants	18
Helson, G. A. H.: Aphid Populations, Ecology and Methods of Sampling Aphids *Myzus persicae* (Sulz.) and *Aulacorthum solani* (Kltb.)	20
Dugdale, J. S.: Structural Characters of the Larva of *Selidosema suavis* (Butler) (Lepidoptera: Geometridae, subfamily Ennominae)	24
Spiller, D.: Resistance of Insects to Insecticides	34
News Item: *Danaus chrysippus petilia* Stoll. breeding in New Zealand	52

Printed by
Otago Daily Times Co., Ltd., Lower High Street, Dunedin, N.Z.